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14

LECTURES

ON

NATURAL PHILOSOPHY.

BY THE

REV. JAMES WILLIAM M'GAULEY, CANON, &c.

PROFESSOR OF NATURAL PHILOSOPHY, AND ONE OF THE HEADS OF THE TRAINING DEPARTMENT TO
THE NATIONAL BOARD OF EDUCATION IN IRELAND.

THIRD EDITION,

ENLARGED, IMPROVED, AND ILLUSTRATED BY 350 WOOD-CUTS.

"Humili vulgo scripta sunt, agricolarum, opificum turbæ, denique studiorum otiosis."

"These things were written for the lowly multitude, for the crowd of agriculturists, and artisans; in a word, for those whose occupations allow them but few opportunities of study."—
PLINY, NAT. HIST., B. I.

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REV. JAMES WILLIAM M'GILLIVRAY, ESQ.

ENTERED AT STATIONERS' HALL.

THIRD EDITION.

LONDON: PRINTED AND SOLD BY J. JOHNSON, ST. PAUL'S CHURCH-YARD.

These three new volumes for the use of schools, and for the general reader, are the result of a long and successful career in the study of the history and principles of the human mind, and of the progress of the human race. They are the work of a man who has spent his life in the study of the human mind, and who has been successful in his efforts to bring the results of his researches to the notice of the general reader.

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PREFACE.

THE latest discoveries and improvements have been, as far as possible, introduced into this enlarged edition.—When the original treatise was written, since it was intended, chiefly, as a means of preparing the teachers in training for my lectures, much was reserved for oral explanation. But I have endeavoured, to adapt the present for private study; and have given in it every detail which is likely to be of any value to those who are desirous of acquiring accurate, though, at the same time, elementary, information. Since no amount of scientific knowledge worth possessing, can be obtained without much labour and assiduity, an attempt to popularize subjects which do not admit of it, must be attended with the worst consequences, and practically illustrate the wisdom of the poet's advice—

“A little learning is a dangerous thing;

Drink deep, or taste not the Pierian spring.”*

None are found to make such gross mistakes, or to fall into so great absurdities, as those who try to learn without trouble, and by the mere hasty perusal of philosophical works. The various branches of experimental science are intimately connected, and serve, often, to explain each other. Hence, numerous references will be found in the following work: and, by means of them, a fact or a principle, that may have been forgotten, can be easily recalled to memory.

* Pope's Essay on Criticism.

Since the different sciences are thus made to illustrate one another, each will be found to have been, in reality, treated at much greater length than might, at first, be supposed from the size of the volume. But, on this account, even to understand what is said on any subject, it will be, generally speaking, indispensable that the student should be fully acquainted with all that precedes it. Those parts of the former work, which relate to arithmetic, algebra, and geometry, have been omitted in the present.—It is my intention to publish them in a separate form: and I have made a commencement, by the larger treatise on arithmetic, which has been used, for some time, in the National Schools.

Throughout the entire treatise, it has been carefully borne in mind, that the philosophy which is best calculated to lead to practical results, and is most likely to benefit the rising generation of artisans, and agriculturists, is alone suited to general diffusion. Every mechanic, who is well acquainted with his business, must be a philosopher: because the principles, upon which the trade of each is founded are, if correct, strictly philosophical. This is not the less certain, because they happen to have been, originally and in less enlightened times, the fruit of practice and experience, rather than of reasoning and experiment—which, only, are the tests of their correctness.

The tradesman, who possesses an adequate acquaintance with philosophy, is likely to purchase improvement in his art, more cheaply than by the mistakes he commits; and to avoid the groundless, and even absurd forms of manipulation, which have been so frequently introduced by ignorance.

For the benefit of those who are not acquainted with mathematical reasoning, any demonstration requiring it has been placed in the notes:—and such persons must be content with imprinting on their minds merely the facts, and principles.

Every element of machinery, and every practical hint, calcu-

lated, in any way, to benefit ingenuity and industry have been introduced. And the treatise on chemistry, has been made sufficiently extensive to include most of what is valuable with reference to the elementary substances, and their chief combinations—particularly so far as agriculture is concerned. It has been kept in view that great numbers of studious, intelligent, and well-educated men are to be found among the National teachers: and that such are very likely to employ their hours of leisure—and even of amusement—in scientific research, but more especially in chemistry. The latter is well adapted to their circumstances; it requires a comparatively inexpensive apparatus: and the field of inquiry which it opens, is so wide, that any one who cultivates it may entertain a reasonable expectation that his researches, if properly directed, will add to the general stock of knowledge. And, without their becoming chemists, in such a sense, as would lead to neglect of their most important duties, the best and happiest results will, undoubtedly, sooner or later follow, from the efforts of so many persons who have devoted themselves entirely to the acquisition, as well as the imparting, of useful information.

The index has been rendered as complete as possible—so that any thing noticed, or explained, can be found at once, under the heads to which it may naturally be referred.

In drawing the illustrations for the wood-cutter, I have made them as simple as possible; but I have tried, also, to render them fully illustrative of what they were intended to explain:—their great number will prove that neither labour, nor expense, has been spared.

JAMES WILLIAM M'GAULEY.

OFFICE OF EDUCATION, DUBLIN,
October, 1851.

SYNOPSIS OF CHAPTERS.

PART I.

CHAPTER I.

MECHANICS.

	Page
Division of the Subject, 1.—Properties of Matter, 3.—The Tides, 17.—Lithographic Printing, 39.—Motion, 40.—Velocity, 42.—Attraction of Gravitation, 54.—Weight, 69.—Momentum, 74.—Reaction, 76.—Collision of Bodies, 77.—The Centre of Gravity, 94.—Composition, and Resolution of Forces, 105.—Circular Motion, 111.—Elliptical Motion, 115.—The Conical Pendulum, 126.—Sources whence Force is generally derived, 144,	1

CHAPTER II.

The Mechanical Powers, 152.—The Lever, 156.—Application of the Lever to the Measurement of Weight, &c., 162.—Combinations of Levers, 177.—The Pulley, 178.—Combinations of Pulleys, 181.—The Wheel and Axle, 191.—The Differential Axle, 192.—Examples of the Wheel and Axle, 194.—Combinations of Wheels and Axles, 196.—Different kinds of Wheels, 201.—Teeth of Wheels, 208.—The Inclined Plane, 224.—Descent of Bodies down Planes, and Curves, 230.—The Wedge, 237.—The Screw, 241.—Application of the Screw, to various purposes, 245,	40
--	----

CHAPTER III.

Regulation of Machinery—Modification of Power, 249.—The Fly Wheel, &c., 251.—The Fuzee of a Watch, 256.—The Pendulum, 257.—The Balance, 278.—The Governor, 284.—Contrivances for Changing the Direction, &c., of Motion, 287.—The Parallel Motion, 295.—The Crank, 297.—The Sun and Planet Wheel, &c., 302.—The Eccentric, &c., 311.—Velocity Combinations, 316.—Gearing, 322.—Reversion of Motion, 325.—Disadvantages incident to Machinery—Friction, 329.—Pressure of Bodies in Motion, 338.—Friction Rollers, 351.—Rigidity of Cordage, 353,	69
---	----

CHAPTER IV.

HYDROSTATICS.

	Page
Objects of the Science: and Division of the Subject, 1.—Pressure of Fluids—Hydrostatic Pressure, 6.—Hydrostatic Paradox, 16.—Bramah's Press, 20.—Hydrodynamic or Hydraulic Pressure, 31.—Surfaces of Fluids, 32.—Levels, 37.—Balloons, 40.—Specific Gravity, 46.—The Hydrometer, 53.—The Specific Gravity Bottle, 55.—Table of Specific Gravities, 65.—Floating Bodies, 67.—The Resistance of Fluids, 69.—Spouting Fluids, 75.—Motion of Fluids in Pipes, &c., 87.—Capillary Attraction, 96.—Hydraulics: Vertical Water Wheels, 108.—Horizontal Water Wheels or Turbines, 122.—Paddle Wheels of Steam Vessels, 135.—Screw of Archimedes, 137.—Screw Paddles, 139.—The Hydraulic Ram, 141,	98

CHAPTER V.

PNEUMATICS.

Objects of the Science, 1.—Properties of the Air, 2.—The Diving Bell, 8.—The Condenser, 10.—The Air Gun, 14.—The Air Pump, 19.—Pressure of the Air, 28.—The Barometer, 30.—Pumps, 44.—Syphons, 53.—Sound, 56.—Conduction, &c., of Sound, 57.—Musical Sounds, 69.—The Gamut, 70.—Sympathy, 77.—Temperament, 83.—Tuning of Pipes, Strings, &c., 88.—Reflection of Sound, 95.—Concentration of Sound, 97.—Interference of Sound, 98.—Buildings for Public Speaking, 99.—Ventriloquism, 103.—The Wind, 104.—Anemometers, 107,	138
---	-----

CHAPTER VI.

OPTICS.

Division of the Subject, 1.—Sources whence Light is derived, 2.—Nature of Light, 3.—DIOPTRICS. Refraction, 9.—Foci of Lenses, 27.—Images formed by Lenses, 35.—The Camera Obscura, 44.—Camera Lucida, 45.—Magic Lantern, 46.— <i>Microscopes</i> . The Single Microscope, 48.—The Compound Microscope, 53.— <i>Refracting Telescopes</i> . The Astronomical Telescope, 59.—CATOPTICS, 65.—Foci of Mirrors, 67.—Images formed by Mirrors, 85.—The Reflecting Microscope, 95.— <i>Reflecting Telescopes</i> —The Gregorian, 96.—The Cassegrainian, 97.—The Newtonian, 98.—Spherical Aberration, 102.—CHROMATICS, 105.—Properties of the Spectrum, 116.—Photography, 120.—The Rainbow, 163.—Interference of Light, 170.—The Eye, 184.—Long and Short Sight, 197.—DOUBLE REFRACTION, 205.— <i>Polarization of Light</i> , 210.—Interference of Polarized Light, 239.—Circular, &c., Polarization, 249,	166
--	-----

CHAPTER VII.

ELECTRICITY.

	Page
History of Electricity, 1.—Electrical Attraction, and Repulsion, 3.—	
Electroscopes and Electrometers, 4.—Examples of Attraction and	
Repulsion, 13.—Electrics and Non-Electrics, 19.—Conductors and	
Non-Conductors, 20.—The Two Electricities, 26.—Circumstances	
which affect the Nature of the Electricity produced by Friction, 34.	
—Induction, 40.—The Leyden Jar, 46.—Distribution of Electricity,	
57.—The Electrical Machine, 62.—Mechanical Effects of Electricity,	
72.—Chemical Effects, 80.—Physiological Effects, 88.—Magnetic	
Effects, 93.—Electric Light, 94.—Atmospheric Electricity, 100.—	
Protection from Lightning, 105,	230

CHAPTER VIII.

GALVANISM.

History of Galvanism, 1.—Nature of Galvanism, 5.—Connexion	
between Galvanism and Electricity, 10.—Apparatus for producing	
Galvanic Electricity, 14.—Various kinds of Galvanic Battery, 23.—	
Effects of Galvanism, 52.—Chemical Effects, 53.—The Electrotpe	
Process, 65.—Physiological, &c., Effects, 110.—Other Sources of	
Electricity, 117,	256

CHAPTER IX.

MAGNETISM.

History, &c., of Magnetism, 1.—Nature of Magnetism, 7.—Dip and	
Variation of the Needle, 11.—Compasses, 18.—Action of the Magnet	
on Iron and Steel, 22.—Action of the Iron in Ships, on the Needle, 27,	287

CHAPTER X.

ELECTRO-MAGNETISM.

History of Electro-magnetism, 1.—Action of the Conductor, on the	
Magnet, 2.—Magnetic Rotations, 6.—The Galvanometer, 8.—Electro-	
magnetic Induction, 12.—Electro-magnetism, as a Moving Power,	
16.—The Electric Telegraph, 20.—Secondary Currents, 24.—Mag-	
netism, produced by Rotation, 35.—Identity of Electro-magnetism,	
and Terrestrial Magnetism, 41,	293

CHAPTER XI.

HEAT.

Importance of Heat, 1.—Theories, concerning the Nature of Heat, 5.—	
Sources whence Heat is derived, 6.—Conduction of Heat, 11.—Radi-	
ation of Heat, 21.—Absorption, and transmission of Heat, 25.—	
Reflection of Heat, 34.—Expansion caused by Heat, 38.—Thermo-	
meters, 51.—Pyrometers, 68.—Specific Heat, 75.—Latent Heat, 77.	
—Evaporation, 83.—The Dew Point, 94.—The Hygrometer, 95.—	
Ebullition, 106.—Freezing mixtures, 114,	305

CHAPTER XII.

THE STEAM-ENGINE.

Page

History of the Steam-engine, 1.—High, and Low Pressure Engines, 7.	
—The Single, and Double Acting Engine, 11.—Details of the Steam-Engine, 14.—Power &c., of Engines, 55.—Expansive Action of Steam, 66.—The Oscillating Engine, 69.—Rotary Engines, 70.—The Marine Engine, 87.—Locomotive Engines, 89.—Locomotive Engines, on ordinary Roads, 98.—Atmospheric Railway, 99.—Proposed Substitutes for Steam, 100,	331

P A R T I I.

CHAPTER I.

INORGANIC CHEMISTRY.

Nature, History, and Division of the Science, 1.—Divisibility of Matter, 8.—The Elements, with their Equivalents, and Symbols, 13.—Chemical Language, 18.—Chemical Processes, 40.—Chemical Apparatus, 72.—Affinity, 115.—Circumstances which modify Chemical Affinity, 126.—Dyeing, 137.—The Laws of Affinity, 142,	365
---	-----

CHAPTER II.

The Elements of Water: Oxygen, 155.—Combustion, 160.—Respiration, 171.—Hydrogen, 180.—Water, 186.—Peroxide of Hydrogen, 198.—Components of Atmospheric Air: Nitrogen, 200.—Atmospheric Air, 204.—Nitrous Oxide, 215.—Nitric Oxide, 218.—Hyponitrous Acid, 220.—Nitrous Acid, 225.—Nitric Acid, 229.—Ammonia, 244.—Tetrachloride of Azote, 257.—Carbon, 259.—Carbonic Oxide, 263.—Carbonic Acid, 266.—Olefiant Gas, 272.—Light Carburetted Hydrogen, 274.—Gases for Illumination: Coal Gas, 276.—Oil Gas, 287,	400
---	-----

CHAPTER III.

Sulphur, 290.—Hyposulphurous Acid, 293.—Sulphurous Acid, 294.—Sulphuric Acid, 298.—Sulphuretted Hydrogen, 311.—Selenium, 316.—Phosphorus, 319.—Phosphuretted Hydrogen, 325.—Chlorine, 328.—Hypochlorous Acid: Bleaching Salts, &c., 339.—Chlorous Acid, 345.—Perchlorous Acid, 346.—Chloric Acid, 348.—Hydrochloric Acid, 351.—Aqua Regia, 358.—Iodine, 359.—Bromine, 364.—Fluorine, 368.—Hydrofluoric Acid, 370.—Silicon, 373.—Silica, 376.—Manufacture of Porcelain, 380.—Manufacture of Glass, 387.—Soluble Glass, 411.—Fluoride of Silicon, 416.—Boron, 421,	440
--	-----

CHAPTER IV.

	Page
THE METALS: their General Properties, 425.—Aluminum, 430.—Antimony, 435.—Arsenic, 439.—Barium, 444.—Bismuth, 453.—Cadmium, 457.—Calcium, 461.—Cerium, 469.—Chromium, 472.—Cobalt, 478.—Columbium, 484.—Copper, 488.—Didimium, 498.—Erbium, 499.—Glucinum, 500.—Gold, 503.—Ilmenium, 510.—Iridium, 511.—Iron, 515.—Steel, 524.—Lanthanum, 539.—Lead, 541.—Lithium, 551.—Magnesium, 555.—Manganese, 559.—Mercury, 565,	473

CHAPTER V.

The Metals continued: Molybdenum, 577.—Nickel, 582.—Niobium, 588.—Osmium, 590.—Palladium, 594.—Pelopium, 598.—Platinum, 599.—Potassium, 607.—Rhodium, 625.—Ruthenium, 631.—Silver, 635.—Sodium, 643.—Strontium, 653.—Tellurium, 656.—Terbium, 659.—Thorium, 660.—Tin, 663.—Titanium, 670.—Tungsten, 674.—Uranium, 679.—Vanadium, 683.—Yttrium, 688.—Zinc, 692.—Zirconium, 697.—Comportment of the Metals, with re-agents, 700, .	513
--	-----

CHAPTER VI.

ORGANIC CHEMISTRY.

Structure of Plants, 1.—The Roots, 6.—The Stem, 13.—Buds, 15.—Leaves, 16.—Digestion, and Respiration of Plants, 20.—The Flower, 26.—The Fruit, 27.—The Seed, 29.—Peculiarities of Organic Elements, and their Compounds, 31.—Oxalic Acid, 42.—Cyanogen, 48.—Hydrocyanic Acid, 53.—Uric Acid, 62.—Acetic Acid, 69.—Formic Acid, 78.—Tartaric Acid, 82.—Racemic Acid, 89.—Citric Acid, 90.—Malic Acid, 94.—Tannic Acid, 98.—Manufacture of Leather, 102.—Gallic Acid, 104,	552
--	-----

CHAPTER VII.

Constituents, &c., of Oils and Fats, 110.—Glycerine, 113.—Stearic Acid, 116.—Margaric Acid, 123.—Oleic Acid, 126.—Butter, 133.—Spermaceti, 137.—Wax, 139.—Soaps, 140.—Manufacture of Soap, 145.—Resin, 149.—Caoutchouc, 155.—Gutta Percha, 158.—Starch, 159.—Lichenine, 163.—Gum, 164.—Sugar, 167.—Lactine, 176.—Mannite, 178.—Diastase, 179.—The Vinous Fermentation, 181.—Brewing, 185.—Distillation, 191.—Alcohol, 194.—Ether, 203.—Manufacture of Bread, 210.—Lignine, 214.—Gun Cotton, 215.—Extractive Matter, 218.—Gluten, 219.—Vegetable Albumen, 221.—Legumine, 222.—Fibrine, 223.—Animal Albumen, 224.—Caseine, 227.—Vegetable Jelly, 231.—Gelatine, 232.—Ozmazome, 234.—Vegetable Alkalies, 235.—Salicine, 236.—Caffeine, or Theine, 238.—Piperine, 240.—The Putrefactive Fermentation, 241.—Last Products of decaying Vegetable Matter, 254,	586
---	-----

CHAPTER VIII.

Constitution of the most important Vegetable Substances, 257.—Ma- nures, 262.—Animal Manures, 265.—Vegetable Manures, 274.— Mineral Manures, 275,	Page 622
---	-------------

CHAPTER IX.

CHEMICAL ANALYSIS.

Nature, &c., of the Process, 1.—Qualitative Analysis of Water, 2.— Quantitative Analysis, 17.—Qualitative Analysis of Organic Sub- stances, 49.—Quantitative Analysis, 55.—Analysis of a Soil, 68.— Organic Constituents of the Soil, 72.—Constituents of the Soil, which are Soluble in Water, 79.—Constituents, which are Soluble in Dilute Hydrochloric Acid, 86.—Constituents, which are Insoluble in Water, and Dilute Acids, 90.—Constituents, which are Insoluble in Water, and Acids, 91,	635
--	-----

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Division of the Subject, 1.—Properties of Matter, 3.—The Tides, 17.—Lithographic Printing, 39.—Motion, 40.—Velocity, 42.—Attraction of Gravitation, 54.—Weight, 69.—Momentum, 74.—Reaction, 76.—Collision of Bodies, 77.—The Centre of Gravity, 94.—Composition, and Resolution of Forces, 105.—Circular Motion, 111.—Elliptical Motion, 115.—The Conical Pendulum, 126.—Sources whence Force is generally derived, 144.

1. DIVISION OF THE SUBJECT.—The sciences which, collectively, constitute what is called “Natural Philosophy” are most intimately connected; and the laws of one are, not unfrequently, to a certain extent identical with those of another.

2. *Matter* is that by means of which physical bodies, or those belonging to the external world, act on our senses. It is either solid, fluid, gaseous, or—perhaps we may add—ethereal. The laws which govern solid matter constitute *mechanics*.^{*}—The latter is divided into *statics*,[†] which relates to matter at rest; and *dynamics*,[‡] which relates to matter in motion. The laws which belong to matter in a fluid state constitute *hydrostatics*, *hydrodynamics*, and *hydraulics*; those which belong to matter in a gaseous state constitute *pneumatics*; and those which belong to matter in an ethereal state constitute *optics*, *electricity*, &c. All these shall be examined, at the proper time.

3. PROPERTIES OF MATTER.—At the commencement of mechanics it is usual to examine the most remarkable properties of matter. These are impenetrability, extension, inertia, attraction, and—its opposite—repulsion.

Impenetrability is that property which prevents two bodies from occupying the same place. We may compress them into the space previously occupied by one; but, after compression,

^{*} *Mēchanē*, a machine. *Greek*.

[†] *Statos*, standing. *Gr.*

[‡] *Dunamis*, power, *Gr.*:—because matter can produce no mechanical effect, unless it is in motion.

each occupies as perfectly distinct a space as before. Matter never fills the entire space which it seems to occupy, for all substances are more or less porous.—Indeed, Sir I. Newton believed that, if the earth were compressed, so that its particles would be in contact, it would occupy no more than the space of one “cubic inch.”

4. *Extension* is that property by which matter occupies some portion of universal space; and *figure* is the boundary of extension. Many bodies have a tendency to assume a definite shape.—Crystalline substances are a striking example of this.

5. *Inertia* is the incapability inherent in matter, either of moving itself when at rest, or stopping itself when in motion. The latter is somewhat difficult to be conceived—since matter in motion is always found gradually to stop of itself; we are, however, to remember that this is due to the external causes which act upon it:—such are friction, the resistance of the air, &c. But for these, matter, once put in motion, would continue to move; as actually occurs with the planets—which revolve at this very moment by virtue of the impulse they originally received. Motion, once produced, may be lost by communication to other substances, but it never can be destroyed, except “by an equal, and opposite.”

6. Our knowledge of inertia renders many things easy of explanation, which otherwise would be inexplicable.—A bullet thrown out of the hand against a pane of glass will break it to pieces; but, fired from a rifle, it will make only a small hole. “Inertia” has, in the latter case, rendered it impossible for the *entire* pane to acquire, with sufficient rapidity, the motion necessary for overcoming the cohesion of its particles, and making it fly in pieces. A spent ball, or one fired with a small quantity of powder, will do more damage to the ship it strikes, and kill more men by the splinters, than one which passes through the side with great velocity. It will also make an aperture which can be less easily plugged. If the muzzle of a gun is stopped with snow, clay, &c., or is immersed in water, or if the charge is not rammed home, it will most probably burst on being fired:—the gunpowder being all exploded before its effect reaches the ball, &c., it does not act upon it sufficiently long to put it in motion, and the barrel itself gives way. The same thing would occur in all cases, if a highly explosive compound were used instead of ordinary gunpowder.

7. Rope-dancers avail themselves of the inertia of a long pole, to prevent themselves from falling down.—The inertia of the pole enables them, to a certain extent, to lean against it, in order to regain an equilibrium: and before it has had time to move away, their balance is adjusted. They bring it back gradually to its former horizontal position.

8. Persons are sometimes astonished at seeing an anvil placed on a man's breast, and struck with a heavy hammer; but the inertia of the large mass in the anvil prevents the *rapid* [6] blow from being communicated to the person beneath.

9. If we attempt to clinch a nail which has been driven into a board, by merely striking its point, it will be forced out of the wood; but if a large hammer, &c., is laid against its head, it may be clinched with ease.—The inertia of the hammer, by preventing it from moving away with sufficient rapidity, causes it to act as if it were a fixed object placed before the nail.

10. When we desire to drive the blade of a chisel, &c., into its handle, we do not strike the blade, for this would injure it; but we strike the handle; which then moves up on the blade—the latter, from its inertia, acting, in some measure, as if it were immovable.

11. *Attraction* is that property which enables one body to draw another towards it—there being, as far as our senses enable us to judge, no bond of connexion between them. *Repulsion*—precisely the opposite—is that property by which one body forces another to move away from it. When a body attracts or repels another, it “acts where it is not;” and thus possesses a power which is extremely curious; and which we are quite unable to explain.

12. There are various kinds of attraction:—for instance, that of *gravitation*, which is inherent in all matter. By means of it, every particle attracts every other particle; and, as far as we can know, it acts at all distances. That of *cohesion*, which prevents bodies from falling in pieces; and which, according to its amount, and the extent to which it is counteracted by the opposite property, repulsion—supposed to be due to heat, but certainly increased by it—causes them to be soft or hard solids, fluids, &c. This kind of attraction is exerted through very small distances. That of *chemical attraction*, which, as we shall see, changes the nature of the bodies on which it acts; and is exerted, also, only at minute distances. There are, besides these, *electrical attraction*, &c.

13. The permanence of the planets of our system in their orbits, is due to the attraction of gravitation*—so called because it is that property which gives rise to what is called “weight:”—they are prevented by the mutual attraction, which exists between them and the sun, from flying off into infinite space. Attraction of gravitation causes a plummet, suspended near a mountain, sensibly to deviate from the perpendicular.—This was proved, by the zenith sector giving different meridian zenith distances for the same fixed stars, according as the observer was at the north or at the south side of Schehallion, a

* *Gravitas*, weight. *Latin*.

mountain in Scotland—on account of the plumb-line being, during the experiments, drawn out of the perpendicular, in opposite directions, by the attraction of the mountain.

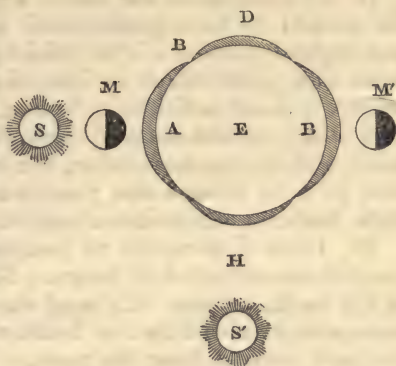
14. Since the attraction existing between every two particles of matter is mutual, the sum of the attractions of two bodies is proportional to the mass of each, when the other is constant; and to their product, when both are variable.

15. The force with which two bodies attract each other depends upon the distance between them; and “varies inversely as the square of that distance.” Hence, when the space between two bodies is doubled, tripled, &c., their mutual attraction is four times, nine times, &c., less. On the other hand, if they are brought twice as near, three times as near, &c., their attraction is rendered four times as great, nine times as great, &c.

16. The attraction of two bodies being mutual, if nothing prevents them, they will both move with the same force; but not, if they are of different sizes, with the same velocity:—for as the same amount of motion will be distributed among a greater number of particles in the one that is larger; each particle of it will have a proportionably smaller quantity. From this principle it follows, that when a stone falls to the earth, the earth moves towards it; but that the distance through which the earth moves is as many times smaller than the distance through which the stone moves, as the number of particles in the former exceeds the number in the latter. This number is—supposing them homogeneous, and of the same shape—as the cubes of their homologous dimensions.—The diameter of the earth is about 8,000 miles; let the diameter of a given sphere of similar materials, falling towards it, be three feet:—the motion of the sphere, falling towards the earth, will then be to the motion of the earth, moving towards it, as the cube of 8,000 miles is to the cube of three feet. The earth will really move; but through a space inconceivably small. Archimedes affirmed that, if another place were given him to fix a machine, he would move the earth:—but he little thought that, while he spoke or wrote this, the alteration in position, however trifling of the matter of his muscles, &c., caused not only the earth, but the entire solar system, and perhaps other and still more stupendous systems, to be moved to an infinitely minute, it is true, but to a real amount. If only one of the mutually attracting bodies is movable, the space it traverses will be twice what it would have been, if both were capable of motion.

17. THE TIDES are a consequence of the attraction of gravitation. The earth revolves on its axis once each day: and the moon is retained in its orbit by the mutual attraction which exists between it and the earth.—The knowledge of these two

facts enables us easily to explain the tides. Let M, fig. 1, and M' represent different positions of the moon, with respect to E, the earth; let S and S' represent different positions of the sun. A and B quantities of water at different sides of the earth, are attracted by the moon M, with very different force, because of their different distances from that planet. Hence A will move much more towards M than either the mass of the earth E, or the water B. In other words, the water A will fall sensibly towards the moon—which of course also falls towards it:—there will, therefore, be a mass of water under M at A; and this mass will be always found under M, although the part of the earth beneath it continually changes, on account of the earth's revolution upon its axis. This mass of water constitutes the *tide* at that side of the earth where it is found. But there must necessarily be a tide, at the same time, on the opposite side of the earth also:—for E and A fall more rapidly towards M, than B, because nearer to M: B therefore is left behind. Hence the waters accumulate, also, at the point farthest from the moon; this accumulation will always be found there, for the reason already given, although the part of the earth beneath continually moves away; and thus a tide is produced at the part of the earth most remote from the moon. The two masses of water are equal; for that which is at B falls as much less rapidly towards the moon than E, as E moves less rapidly towards the moon than A. The water flows in from all directions to form these masses; and, at each side, in the spaces between them, there is the least water:—that is, in these intermediate places, the tide is *out*.



18. While the water is flowing towards the parts which are under the moon, currents are produced which are affected by the interruptions they meet with from islands, promontories, &c. They are modified, also, by the motion which they receive being compounded of two motions—and being therefore, for reasons I shall explain presently, in the direction of neither of them. One of these motions tends to bring the water towards the equator, to supply the place of that which is drawn away by the moon; the other is opposite to the direction of the earth's rotation on its axis, and is due to the water coming from the poles, not having so great a velocity as the parts of

the earth towards which it flows, and being therefore left behind.

19. The inertia of the water, which [6] makes it impossible for motion to be communicated to it instantaneously, causes the highest portion of the tidal wave to be at some distance from that point which is immediately under the moon; and where, without sufficient reflection, we might expect it to be.—The waters cannot *suddenly* obey the force of the moon's attraction; and, in the mean time, the earth revolves a little on its axis, so as to bring a new point under the moon. Hence, it is high water on a meridian about 30° eastward of the moon.

20. These facts enable us to understand why there should be two tides in twenty-four hours. There is a tide on a given side of the earth, because it is *next* the moon, and another on the same side in about twelve hours after, because it has become the part *farthest* from the moon.

21. The tide is later in any place on each succeeding day :—because the given place will not return to its former position in less than a day : and it has, besides, to follow the moon, which in the mean time, has moved on in its orbit.

22. The sun also causes tides; but, although it is much larger than the moon, its effect on the water is much less, on account of its greater distance.—Sir I. Newton has shown that the action of the moon is three times as great as that of the sun. When the sun and moon are in conjunction, that is, at the *same* side of the earth—for instance at S and M, or in opposition, that is, at *different* sides, as at S and M'—or, in other words, at new and full moon there are *spring* tides; because the effects of the sun and moon are then united. The spring tides are not highest, however, exactly at new or full moon, but a little after. When the effects of the sun and moon are opposed, as at S' and M or M'—the moon being in quadrature, there are *neap* tides.

23. The tides are variously affected by the sun—which brings them on sooner, when the moon is in her first and third quarters; but keeps them back when she is in her second and fourth.

24. When the sun or moon, or both, are nearest to the earth, the tides produced by them are highest.—Hence the tides are greatest after the autumnal, and before the vernal equinox; because the sun is nearer to the earth in winter than in summer.

25. If the sun or moon were actually at the pole, the water would not be raised unequally at different parts of the equator, or any parallel of latitude.—Hence the nearer the sun or moon to the pole, the less the inequality in the height of the water, and the nearer to the equator, the greater. Spring tides, therefore, are highest, and neap tides lowest, about the time of the equinoxes; but on the contrary, spring tides are lowest, and

neap tides highest, at the solstices. When the moon is in the equator, both the tides of the lunar day—the time which the moon takes to return again to the same meridian—are equal, at places having a northern or southern latitude. But as she declines to either pole, the two tides which occur at the same time are not in the same parallel, but in different ones:—and hence the highest point of one of the tides—that at which the moon is nearest to the zenith—will be nearer to the given place than the highest point of the other, since one of the parallels will be nearer to it than the other.

26. There is no doubt that the action of the sun and moon produces tides in the atmosphere.

27. *The attraction of cohesion*, or “molecular attraction,” is that which keeps the particles of the same mass of matter together. It may be exemplified by rubbing strongly against each other the flat sides of two hemispheres of lead:—they will adhere, and with considerable force. This adhesion is not to be attributed to the pressure of the atmosphere on their convex surfaces, on account of no air being between them:—for the effect is the same when they are placed under the exhausted receiver of an air-pump.

28. The cohesion existing between the particles of fluids may also be easily illustrated.—If a thin plate of any substance, capable of being wetted with water, is suspended horizontally from the beam of a balance, and nicely counterpoised, very little additional weight will cause it to ascend; but if it is made to lie on the surface of water, it will require a comparatively large weight to raise it. The additional weight is rendered necessary by the force which must be expended in separating, from the general mass of fluid in the vessel, the particles of water adhering to the plate.

29. In many instances, all that is required to make bodies cohere, is to bring them sufficiently near each other.—In plate glass manufactories, after the sheets intended for mirrors have been finished and laid together, it has been sometimes found impossible to separate them without breaking; and the aggregated masses have even been cut, and have had their edges polished, as if they formed but one piece.

30. It is probable that the attraction of cohesion may cause rubbing surfaces to wear more rapidly, by bringing them more closely together; and the friction, from this cause must naturally be greater when the rubbing surfaces are of the same material.—Hence, one reason why metals of the same kind do not work well together.

31. The cohesion of the particles of different bodies varies greatly. The following table shows the weight required to tear asunder a prism of the following substances, having a sec-

tion equal to one square inch ; and also, what length of each would break by its own weight :—

	Lbs.	Feet.
Memel Fir,	9,540	40,500
Sycamore,	9,630	35,800
Elm,	9,720	39,050
Oak,	11,880	32,900
Beech,	12,225	38,940
Larch,	12,240	42,160
Christiana Deal, . .	12,346	55,500
Teak,	12,915	36,049
Ash,	14,130	42,080
<hr/>		
Cast lead,	1,824	348
Cast tin,	4,736	1,496
Yellow brass, . . .	17,958	5,180
Cast copper, . . .	19,072	5,003
Cast iron,	19,096	6,110
English malleable iron,	55,872	16,938
Swedish ditto, . . .	72,064	19,740
Cast steel,	134,256	39,455

That is, a bar of steel 39,455 feet long, suspended vertically, will break by its own weight.

32. An iron bar 1,000 inches long, and an inch square, will be lengthened one inch by a weight of 36,000 lbs.

2 inches by	45,000
4 "	54,000
8 "	63,000
16 "	72,000

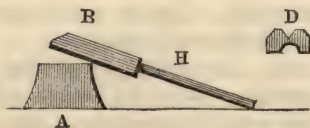
and will then break.

Tenacity is, sometimes, greatly increased by wire-drawing or hammering—copper being nearly doubled, and lead more than quadrupled in strength by these processes. But the consolidation is produced chiefly at the surface:—hence a slight notch with a file will often seriously diminish the strength of a metallic rod.

33. Besides attraction, the antagonist force, called “repulsion,” is found to exist between the particles of all bodies ; and prevents their being brought nearer than within a certain distance of each other. It is perhaps due to heat, and certainly is always modified by an increase or diminution of it.

34. The repulsion arising from heat may be curiously exemplified by placing a ground bar of copper B, fig. 2, about five inches long and half an inch thick, and attached to about eight inches of thick iron wire H, on a cold flat block of lead A. When the lead

FIG. 2.



becomes heated, it raises up the brass by its repulsive power, and when it cools, the brass falls. The repetition of this gives rise to a kind of musical sound, which will continue until the temperature of the metals becomes uniform. The shrillness of the sound is greatly increased by a channel cut in A or in B:—a section of the latter is seen at D. Brass and lead answer best for this experiment, on account of the great difference between their conducting powers.

35. When bodies are affected by repulsion, the result may be anticipated, from what has been said regarding attraction [14, &c.] Thus when a gun is discharged, the ball and the closed end of the gun are separated by the mutually repulsive actions of the particles of gas generated: and the effect continues until the ball passes into the external atmosphere. The amount of motion, therefore, in the gun and its carriage will be nearly equal to that of the ball and half the weight of the powder moving with the same velocity as that of the ball. Supposing a twenty-four pounder to be 10 feet long, and to weigh 6,400 lbs., and the charge of powder to be 8 lbs, the motion of the ball and half the powder, while *they* are in the gun, may be represented by $24 + 4 \times 10 = 280$. But, as the cannon weighs 6,400 lbs., its motion will be $\frac{280}{6400} = \frac{7}{160}$ of a foot, or half an inch nearly.

Such, therefore, would be the recoil of the gun, if it were free to move:—and its velocity would be as much less than that of the ball, &c., as it would exceed them in weight. It is scarcely necessary to remark that this would be its motion during the passage of the ball through it: and it would continue to move for some time afterwards.

36. Glass lenses are used in optics for the production of coloured rings—for which purpose they are merely, as we shall see, pressed together; if they are heated, the rings will close in, which shows that the repulsion caused by the heat, has separated the pieces of glass to a greater distance than before.

37. The repulsion produced in this way may be exemplified, also, by pouring a drop of water into a platinum crucible, raised to a red heat. The water will not come into contact, in such circumstances, with the metal, and it is possible to render the space between them distinctly visible; which causes the evaporation, even of a highly volatile liquid, to be exceedingly slow. Fluids in this state have an ellipsoidal, or when in small quantity, a spheroidal form, and revolve with great rapidity, on a changeable axis. And under these circumstances their very properties are altered:—a surface of copper or of silver is not acted upon by a spheroid of nitric acid; nor a surface of zinc or iron by a spheroid of dilute sulphuric acid. Anhydrous sulphureous acid boils, in ordinary circumstances, at 14° ; but in the spheroidal

form, its evaporation is scarce perceptible; and what is very curious, a quantity of water projected upon it will be frozen; so that ice may be produced in a vessel intensely hot. This is supposed by some to arise from the rapid absorption of the vapour of water, by the sulphureous acid: but it is most probably due to the rapid evaporation of the acid, which boils at so low a temperature. Mercury has been frozen by plunging it into a spheroid of ether and solid carbonic acid.

38. We may exemplify the repulsion of one body for another, at ordinary temperatures, by carefully placing a small needle on the surface of water:—it will repel the latter, to such an extent, that so large a hollow will be formed as will cause the water displaced to be heavier than the needle; which, therefore, will float.

39. LITHOGRAPHIC PRINTING.—The attraction and repulsion exhibited by different substances towards each other are beautifully applied to practical purposes, in the process of *lithography*.* The drawing, &c., to be lithographed, is written with a peculiar kind of ink—between which and water there is a strong repulsive action—and is transferred by pressure to a fine grained and very porous stone; or a reverse drawing is made at once on the stone. When an impression is to be taken, the stone is wetted, and freely absorbs the moisture, except in those places that have been inked, which, therefore, will repel the water, and remain quite dry. A roller, containing the same kind of ink, is next passed over the stone, and the ink adheres only to those places which have repelled the water, the other parts remaining perfectly clean.—So delicate is the manipulation required in this process, that touching the stone with the finger will leave an unctuous mark to which the ink would adhere, and which therefore would be accurately, though unintentionally, transferred to the paper, in printing. When the stone is inked the paper is placed upon it, and pressure is applied.

Another kind of attraction is called “capillary.” It is, however, as I shall show when I treat of hydrostatics, only a modification of molecular attraction.

40. MOTION is simply “change of place;” and it is greater or less, according as that change is greater or less—no regard whatever being had to the time in which the change is effected.—Thus, if one body moves five inches in a second, and another five inches in 5,000 years, the motion of both is the same. But if one body moves fifty feet in one minute and then stops, and another moves forty-nine feet per second, for two seconds, and then stops, the motion of the former will be *less* than that of

* *Lithos*, a stone; and *Grapho*, I write. *Greek*.

the latter. Motion is “proportioned to the space over which the body, which has it, would travel.”

Any thing that produces motion is called a *force*.

41. Motion is said to be either “absolute” or “relative.” Absolute motion is actual change of place.—Thus, when a horse gallops, his motion is absolute. Relative motion is change of distance from another object.—Thus, if two horses gallop with equal rapidity in the same direction, they will have no relative motion; but if they move with different rapidities in the same direction, their relative motion will be the difference between their absolute motions. If they move in opposite directions, their relative motion will be the sum of their absolute motions. A body may be absolutely at rest, though relatively in motion:—thus, the shore is in motion, with reference to a ship putting out to sea.

42. VELOCITY is quantity of motion with regard to a given time—no attention being paid to the entire space traversed. Hence one body may move with a greater velocity than another; though, on the whole, it changes its place to a less extent.

43. The farther a body is from the centre of motion, the greater its velocity.—For, if two bodies A and B, fig. 3, are immovably connected by an inflexible rod, each will describe round C, the centre of motion, an arc which will measure the same angle:—that is, the “angular velocity” of both will be the same. But arcs, having the same number of degrees, are as the radii which describe them. And the given arcs are the spaces described, respectively, by the bodies A and B; their radii being the distances of A and B from C, the centre of motion. Therefore, since these spaces, or arcs, are proportional to the velocities of A and B—because described in equal times—the velocities of A and B are proportional to their distances from C.

FIG. 3.



44. Hence the velocity of a body at or near the equator, is greater than that of one which is at, or near, the poles.—The water, therefore, as it flows from the poles towards the equator [18], not having the velocity of the earth at those points over which it passes, is left behind in the diurnal revolution.

45. Velocity is either *uniform* or *accelerated*; and, if the latter, it is either *uniformly* or *variably* accelerated. When the velocity is uniform, it is the same at every period, during the time of motion; and “the spaces described, under its influence, in equal times will be equal.” Hence, when the velocity is uniform “the whole space described is equal to the velocity—or space described during a unit of the time—multiplied by the time.” That is, calling the space S: the velocity V: and the time T: $S = TV$. For if a body travels during 10" with a velocity of 40 feet per second, it will have travelled $10 \times 40\text{ft.} = 400\text{ft.}$

46. And the greater or less the time, the greater or less the space; that is, "the space is proportional to the time;" or $S \propto T$.

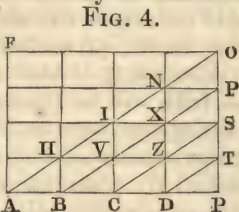
47. "The velocity is equal to the space divided by the time," or $V = \frac{S}{T}$. For, if a body travels 400ft. in 10", it travels $\frac{400}{10}$ ft., or 40ft. in $\frac{10''}{10}$, or 1".

48. "The time is equal to the space divided by the velocity," or $T = \frac{S}{V}$. For, if a body travels 400 feet with a velocity of 40 feet per second, the time required is $\frac{400''}{40} = 10''$.

49. When the velocity is *accelerated* it is greater at successive periods; and if it is *uniformly* accelerated, "the increments of velocity will be equal, in equal times." Uniformly accelerated velocity is produced by a uniform force *continuing* to act.

50. With a uniformly accelerated velocity "the space varies as the square of the time, or of the last acquired velocity."—

For, indicating the times and spaces traversed, by lines proportional to them; and considering the velocity as uniform during each indefinitely short period of time; let A P, fig. 4, representing the



entire time, be divided into equal portions by B, C, and D. At A, the velocity with which motion commences, is nothing; and the space traversed by means of it may be represented by a point. At B it has increased so that the space, corresponding to that instant of time, will be represented by B H. At C it will be represented by CV+VI=2BH:—for BH must be the increment in each successive equal period. In the same way, at D, the space is equal to DN; and at P, to PO. At all the points between A and P the spaces would be represented by uniformly increasing lines which, together, would form the triangular surface AOP:—therefore the surface AOP will represent the space traversed in the whole time AP. Hence the space traversed in the times AB, AC, &c., is to the space traversed in the time AP, as the triangles having these lines for their bases:—or, since these triangles are similar surfaces, as the squares of their homologous dimensions. But the lines AB, AC, &c., are their homologous dimensions—and also represent the times; therefore the spaces are as the squares of the times. BH, CI, &c., likewise, are homologous dimensions—and represent the last acquired velocities: hence the spaces are as the squares of last acquired velocities also.

51. The spaces described in successive portions of time, AB,

BC, CD, &c., are as the odd numbers 1, 3, 5, &c.; this will be evident on inspecting the surfaces representing the spaces:—for $BHIC=3AHB$; $CIND=5AHB$, &c.

52. The space traversed under the influence of a uniformly accelerating force is only one-half of what it would have been, had the last acquired velocity been the velocity at every instant.—For, let PO, fig. 4, the last acquired velocity, be the velocity at every instant of the time represented by AP, then the space described at each instant—corresponding to each point of AP—would be represented by a line=PO:—but a series of such lines would form the rectangle $AFOP=2AOP$ —that is, twice the space described when the velocity is uniformly accelerated.

53. The laws which relate to a uniformly accelerating force are applicable also to a uniformly retarding one; which may be considered as a uniformly accelerating one, in an opposite direction; and which, therefore, destroys as much velocity as it would have generated in the same time, had it been an accelerating force.

54. ATTRACTION OF GRAVITATION.—A body is found to fall, under the influence of gravity, about $16\frac{1}{2}$ feet per second.* In estimating the effect of gravity, considered as a uniformly accelerating or retarding force, the resistance of the air is not taken into account; nor the difference of the force of gravity, at different distances from the earth's surface.—The latter, however, must be small; for the action of gravity at the surface of the earth is to its action at any distance from it, as the square of the earth's radius plus the distance, is to the square of the earth's radius:—that is, x being the distance, as $(4,000+x)^2$ is $4,000^2$. But, since x must always be inconsiderable, it may be neglected; and the ratio may be looked upon as one of equality.

55. To find the space traversed under the influence of gravity when the time is given.—“Multiply $16\frac{1}{2}$ feet by the square of the time.”†

EXAMPLE.—A stone takes 3" to reach the bottom of a precipice; what is the depth of the latter? $16\frac{1}{2} \times 3^2 = 16\frac{1}{2} \times 9 = 144\frac{3}{4}$, the depth of the precipice.

56. To find the space, when the last acquired velocity is given “Divide the square of the last acquired velocity by $64\frac{1}{2}$.”‡

* In the latitude of London it falls 16.095 feet.

† Let S be the space through which the body falls; let g be the force of gravity, at the end of the first second, which is equal to $[52] 32\frac{1}{2}$ feet.—Then $[50]$

$S = \frac{gt^2}{2}$:—that is, the space described in one second, multiplied by the square of the number of seconds.

‡ For, v being the last acquired velocity at the end of any period of time, $v=gt$ —or the velocity at the end of the first second, multiplied by the number of seconds,

$[50]$; $v^2 = g^2t^2$; and $\frac{v^2}{2g} = \frac{g^2t^2}{2g}$. But $[55] S = \frac{gt^2}{2} = \frac{g^2t^2}{2g}$; Therefore $S = \frac{v^2}{2g}$.

EXAMPLE.—How far will a body fall to acquire a velocity of 1,500 feet per second? $1,500^2 \div 64\frac{1}{2} = 34974.0933$ feet.

57. To find the last acquired velocity when the time is given. “Multiply the time by $32\frac{1}{6}$.”*

EXAMPLE.—If a body continues falling for $9.5''$, what will be its last acquired velocity? $9.5 \times 32\frac{1}{6} = 305$ feet 7 inches.

58. To find the last acquired velocity when the space is given. “Multiply twice the space by $32\frac{1}{6}$, and take the square root of the product.”†

EXAMPLE.—What will be the last acquired velocity of a body that has fallen 1,000 feet? $\sqrt{2 \times 1,000 \times 32\frac{1}{6}} = 253.64$ feet.

59. To find the time, when the last acquired velocity is given. “Divide the velocity by $32\frac{1}{6}$.”‡

EXAMPLE.—For how many seconds must a body fall, to acquire a velocity of 1,600 feet per second? $1,600 \div 32\frac{1}{6} = 50''$, nearly.

60. To find the time when the space is given. “Divide the space by $16\frac{1}{2}$: and take the square root of the quotient.”§

EXAMPLE.—How long will a body take to fall 1,189 feet? $\sqrt{1189 \div 16\frac{1}{2}} = 8.6''$.

61. A uniformly retarding follows the same laws as a uniformly accelerating force; except that instead of generating, it destroys velocity.

EXAMPLE.—If a body is projected upwards with a velocity of 1,690 feet per second, how far will it ascend before it stops; and how long will it take to return to the earth?—Gravity [56] will generate a velocity of 1,690 feet per second by falling 44,395 feet nearly; and that space [60] would be traversed in $52.54''$ nearly.—It will therefore travel 44,395 feet and then stop; but it will return to the earth in the time it took to ascend. Hence it will reach the earth in $2 \times 52.54'' = 105.08''$: and will have travelled 88,790 feet nearly.

62. When a body is projected upwards, its velocity at every point of its ascent is as the square root of the space it has still to describe.¶ And, at every point during descent, it will have the same velocity as it had at that point during ascent.

63. If a body have an initial velocity—that is, if when gravity begins to act, it is already in motion, through the influence of some other force—“we must *add* the space that would be traversed under the influence of the force producing that

* Since [50] $v = g t$.

† For since [56] $S = \frac{v^2}{2g}$; $v^2 = 2gS$; and $v = \sqrt{2gS}$.

‡ For, since [50] $v = gt$; $t = \frac{v}{g}$.

§ Since [55] $S = \frac{gt^2}{2}$; $t^2 = \frac{2S}{g}$; and $t = \sqrt{\frac{2S}{g}} = \sqrt{S \div \frac{g}{2}}$.

¶ $S \propto v^2$ [50].—Therefore $v \propto \sqrt{S}$.

velocity, to the space through which gravity would cause the body to pass in the same time."

EXAMPLE.—A body is projected downwards with a velocity of 100 feet per second; how far will it have descended in 5"?

Under the influence of its initial velocity, it would, in 5" travel 500 feet [45]. Under the influence of gravity, it would travel, in the same time, $25 \times 16\frac{1}{2}$ [55] = $402\frac{1}{2}$ = feet.—Therefore, under the influence of both, it will travel $500 + 402\frac{1}{2} = 902\frac{1}{2}$ feet.

64. If a body is projected upwards, the space it would have travelled in the given time, under the influence of gravity, must be *subtracted* from the space it would have traversed, under the influence of its initial velocity.

65. We may find the space described by a body under the influence of gravity, during any particular second, "by adding $16\frac{1}{2}$ feet to the last acquired velocity of the preceding second;" since this is the increment during each second.

EXAMPLE.—If a body continues falling for 6", how long will it have travelled in the sixth second?—Its last acquired velocity at the end of the fifth second will be $5 \times 32\frac{1}{2}$ [57]; hence it will have fallen in the sixth second, $5 \times 32\frac{1}{2} + 16\frac{1}{2} = 176\frac{1}{2}$ feet.

66. Knowing the space travelled over in the last second, we can ascertain how long a body has been falling; and how far it has fallen.

EXAMPLE.—A body falls through half its descent, in the last second; how long was it falling, and how far did it fall? Let t represent one less than the number of seconds. In t'' it fell $\frac{S}{2}$ or half the space; it also fell $[55]t^2 \times 16\frac{1}{2}$ feet:—therefore $\frac{S}{2} =$

$t^2 \times 16\frac{1}{2}$. It fell in the last second $\frac{S}{2}$, or half the space; and

also $[65]t \times 32\frac{1}{2} + 16\frac{1}{2}$, therefore $\frac{S}{2} = t \times 32\frac{1}{2} + 16\frac{1}{2}$; putting

both the values of $\frac{S}{2}$ equal, we have $t^2 \times 16\frac{1}{2} = t \times 32\frac{1}{2} + 16\frac{1}{2}$,

and from this equation we find $t = 2.4142''$. Hence $t+1 = 3.4142''$, the whole time of falling.—Consequently [55] the space travelled over during the last second is 93.76 feet; and the whole space through which it falls $2 \times 93.76 = 187.52$ feet.

67. If the entire weight of a falling body is not effective, the space through which it moves in a given number of seconds is equal to "the space through which it would have fallen, multiplied by the quotient obtained by dividing its effective part by the entire mass to be moved."*

* Calling $W - W'$ the effective part; t the number of seconds; and S the space traversed by the whole mass; the space traversed by the mass will be as much less than what would have been traversed by the effective part—if it acted alone—

EXAMPLE.—Two weights, one 7 lbs. and the other 13 lbs., are suspended over a pulley. How far will the former ascend and the latter descend in 2" ? $2^s \times 16\frac{1}{2}[55] \times \frac{13-7}{13+7} = 19.3$ feet.

68. If there were an aperture through the earth from pole to pole; supposing the earth's axis to be 7,900 miles, and that a body were to fall along it; the velocity of that body, at the centre of the earth, would be 25,834 feet per second; and its passage to the opposite pole would be made in 42' 16 $\frac{1}{4}$ ".

69. WEIGHT.—The attraction of the earth for bodies on its surface gives rise to what is called "weight." As each particle of a body is individually attracted, the sum of the attractions—or the weight, will be proportional to the number of particles—no reference being had to size. Weight, therefore, is used as a means of ascertaining the quantity of matter contained in a body.

70. The nearer a body is to the earth, the more it will weigh. Ordinary changes of distance, however, do not produce a sensible effect; and a difference becomes perceptible only when the change of distance is considerable.—1,000 lbs., on the surface of the earth would, if carried to the top of a mountain four miles high, show, by means of a spring balance, a loss of weight equal to 2 lbs. But, if carried four miles into the earth it would show a loss of 1 lb.—its greater proximity to the centre of gravity of the earth being more than counterbalanced by the action of the mass above it.

The force of gravity decreases from the poles to the equator.—1,000 lbs., carried from this to the pole, would gain 3 lbs.; but carried from this to the equator it would lose 4 $\frac{1}{4}$ lbs.

71. The same body would have a different weight in different planets. A cubic inch of lead weighs, on the surface of the earth, 6 $\frac{1}{2}$ oz.; in the sun it would weigh 11 $\frac{3}{4}$ lbs.

72. The earth is nearly four times as dense as the sun; but the latter is so much larger than the former, that a man of moderate size would weigh two tons on its surface; and, with his present muscular strength, he would be unable even to move. In any of the newly-discovered planets he would weigh but a few pounds.

73. *Meteoric Stones* are thought, by some, to be bodies projected from volcanoes in the moon, with such a velocity as to carry them out of the sphere of the moon's, and within the sphere of the earth's attraction. It is calculated that, if one of them were projected with the initial velocity of 10,992 feet per

as the mass is greater than the effective part. For the quantity of motion being the same in both cases, the larger the mass, the smaller the space it will traverse;—that is, $W + W' : W - W' :: t' \times 16\frac{1}{2} : S$. Therefore $S = t^2 \times 16\frac{1}{2} \frac{W - W'}{W + W'}$

second—or with more than four times the velocity of a ball, just discharged from a cannon, it would come within the sphere of the earth's attraction, and revolve round it like a satellite: and the primitive impulse, if sufficiently great, might at once, or the disturbing influence of the sun might, after a time, precipitate it to the earth.—Its velocity in passing through the air would, it is supposed, cause ignition. Meteoric bodies of great magnitude occasionally approach very near the earth.—One of them, estimated to be 600,000 tons in weight, and moving with a velocity of 20 miles per second, passed within 25 miles of it. Only a small fragment, however, reached the earth.

All meteoric stones are found to be almost identical in composition.

74. **MOMENTUM** may be defined “the effect producible by a given quantity of matter, possessing a given amount of motion;” or “the quantity of motion which may be imparted by one body to another.”—For, the entire effect which one body is capable of producing on another is, ultimately, reducible to the quantity of motion it is capable of imparting to the other. In estimating momentum, both the mass and velocity are to be taken into account; for momentum cannot exist without both of them:—if either of them is invariable, momentum is proportional to the other; and if both are variable, it varies as their product. Nothing affects momentum, unless it affects the mass or velocity—or both. To increase the momentum we must increase the quantity of communicable motion; and this may be effected either by adding to the body, having the momentum, a number of particles, each possessing the same motion as those to which they are added—which is “to increase the mass,” without altering the velocity; or, by adding to the motion of each of the particles, without increasing their number—which is “to increase the velocity,” without altering the mass; or, finally, we may increase the quantity of communicable motion, by increasing both the number of particles, and the quantity of motion existing in each. Calling the momentum M ; the quantity of matter, or number of particles Q ; and the velocity V ; the changes produced on the momentum by altering the mass, or velocity, or both, are thus briefly expressed:—

$M = QV$.—Therefore, M is directly proportional to Q , when V is constant; but to V , when Q is constant: and, to their product, when both are variable.

Q is inversely proportional to V , and V is inversely proportional to Q , when M is constant.

EXAMPLE 1.—What must be the velocity, to produce, with a mass represented by 27, a momentum represented by 162?

$$M = QV : \text{—that is, } 162 = 27 \times V$$

$$\text{Therefore } V = \frac{162}{27} = 6, \text{ the required velocity.}$$

EXAMPLE 2.—What must be the mass, to produce, with a velocity represented by 16, a momentum represented by 144 ?

$$M = QV ; \text{ that is } 144 = Q \times 16$$

$$\text{Therefore } Q = \frac{144}{16} = 9 ; \text{ the required mass.}$$

EXAMPLE 3.—A certain momentum is produced by a velocity represented by 15, and a mass represented by 100. But it is found inconvenient, to use a mass greater than 75 :—what must the velocity be, to leave the momentum as before ?

Q is inversely proportional to V :—therefore
 $100 : 75 :: \text{the required velocity} : 15.$

$$\text{Hence, the required velocity} = \frac{100 \times 15}{75} = 20.$$

A mass represented by 100, with a velocity expressed by 15, will produce the same momentum as a mass represented by 75, and a velocity by 20. For

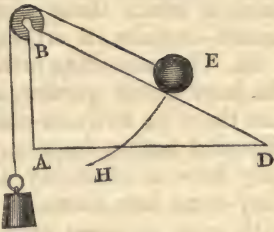
$$100 \times 15 = 75 \times 20.$$

75. Although two momenta are equal, when the products of the masses and velocities are equal, we are not to suppose that the *relative* amounts of the mass and velocity, are of no consequence.—For example, the momentum of a large hammer, with a small velocity, and that of a small hammer, with a large velocity, may be equal ; and yet it would be incorrect to conclude, they may be used indiscriminately. The small hammer will drive a nail, without shaking the object into which it is driven, while the large one would overturn, or shatter it :—for the small one moves so fast, that there is not sufficient time [6] to overcome the inertia of the body, into which the nail is driven. On the other hand, it is found most advantageous, in certain processes, to use enormous hammers, moved by steam ; although much smaller ones would, the velocity being sufficiently great, produce the same momentum.

76. REACTION, is action equal, and opposite to a given one. When bodies are at rest, it is opposed to pressure, &c., and prevents the motion which, without it, would occur.—Thus, a body lying on a table, cannot fall to the ground, from the difficulty of compressing the particles of the table, on account of their mutual repulsion. The reaction of a body is always perpendicular to its surface.—This is evident, when there is question of a body, kept at rest by reaction only : as, when it is on a perfectly smooth and horizontal plane ; but it is equally true when it is kept at rest, by two or more forces.—Let E , fig. 5, be a body, retained on the surface BD by a cord. The only motion

the cord will allow E to receive from gravity, must be, such as would cause it to traverse the curve, indicated by the dotted line E H:—but this curve is perpendicular to B D, at the point of contact. The inclined plane, therefore, prevents motion in a direction perpendicular to its surface—which could be effected only by an equal force, acting in an opposite direction: that is, in a direction, also, perpendicular to B D. Hence the reaction of B D is perpendicular to it.

FIG. 5.



77. COLLISION OF BODIES.—When reaction has reference to one or more bodies actually in motion, or capable of being moved, it is said to arise from *impact*, *percussion*, or *collision*.—Percussion differs from pressure, only by requiring a shorter time to produce its effect. Percussion is *direct*, when it is in a line passing through the common centre of gravity of the bodies coming into collision, and is perpendicular to the plane of impact. It is *oblique*, even though it be in a line perpendicular to the plane of impact, if this line does not pass through the common centre of gravity. The laws which govern oblique may be easily discovered, from what I shall say of direct impact, and of the “composition and resolution of forces.”

78. When reaction arises from impact, the body which is struck may, or may not, be in motion; and neither, or both of the bodies may be perfectly elastic.—A “perfectly elastic body” is one that recovers its shape, with a force equal to that which compressed it. A “perfectly non-elastic body” is one that has no tendency whatever to recover its shape, when compressed: or one that is incapable of compression. No substance in nature is either perfectly elastic, or perfectly non-elastic; though many are, without any sensible error, considered as such. I shall confine myself to perfectly elastic or perfectly non-elastic bodies:—if only one is elastic, or neither is *perfectly* elastic, the effect will be modified, but in a way that can be anticipated from the principles I am about to develop. Reaction, when produced by impact, arises from the repulsion of the particles of the bodies:—force is expended in overcoming this repulsion, but when the body is elastic, it is afterwards restored—though changed to an opposite direction—by the elasticity, which the same repulsion has produced.

79. When bodies come into collision, the sum of their momenta, in any direction, is the same after, as before their collision:—for nothing can diminish this sum, but a momentum in the opposite direction; and none such is considered to be in action.

80. Since, after collision, the sum of the momenta in any

given direction, remains unchanged, the centre of gravity—a point at which these momenta may be supposed to be concentrated—retains its original rest, or motion.

81. The preceding principles afford us a means of determining the laws which govern, either non-elastic, or elastic bodies.—Let there be two non-elastic bodies A and B; V being the velocity of A before impact; and V', that of B before impact. As they have no elasticity, there is nothing to separate them, after they come into contact; they, will, therefore, move on together with some common velocity:—let this be v . Since the sum of their momenta, in the direction of the motion of A, is the same after, as before impact—

$$AV + BV' = \overline{A+B}.v; \text{ and}$$

$$v = \frac{AV + BV'}{A+B}$$

This equation will enable us to find any one of the quantities, which may be unknown.

EXAMPLE.— $A=6$, and $B=6$; $V=11$, and $V'=-11$, being in the direction opposite to V.—Then

$$\frac{AV + BV'}{A+B} = \frac{6 \times 11 - 6 \times 11}{6+6} = 0.$$

Consequently, the bodies will, after impact, remain at rest.

82. *The Ballistic Pendulum* is a machine which is used for estimating the velocities of cannon balls; and depends on this equation. It consists of a large block of wood, attached to the end of a strong iron stem, vibrating on a horizontal axis—like the pendulum of a clock. The ballistic pendulum being at rest, the cannon ball is fired into the block; and remaining within it, causes the whole apparatus to vibrate—the arc being greater or less, according to the velocity of the ball. The extent of the vibration is ascertained by means of a graduated arc, placed under the pendulum, and an index attached to the block. The velocity of the pendulum is calculated, from the arc of vibration; and the velocity of the cannon ball, from that of the pendulum.

83. If the bodies are perfectly elastic, let the velocity of A after impact be v , and that of B, v' . As the sums of the momenta before and after impact are equal [79], $AV + BV' = Av + Bv'$. And

$$v = \frac{2BV' + A - B.V}{A+B}$$

$$v' = \frac{2AV - A - B.V^*}{A+B}$$

84. We may find, from these equations, the value of any one of the quantities contained in them.

* For, during an indefinitely short space of time, the two bodies will, after

EXAMPLE 1.—Let $A=B$; $V=10$; and $V'=0$. Substituting these values we get

$$v = \frac{0}{A+B} = 0$$

$$v' = \frac{20A}{2A} = 10$$

A will, therefore, cease to move; and B will move, with the former velocity of A.

EXAMPLE 2.—Let $B=A$; $V=100$; and $V'=20$:—

$$v = -6.666, \text{ and}$$

$$v' = 73.333, \text{ \&c.}$$

A will, therefore, after collision, have a negative motion—or one opposite to that which it had before; and B a positive—that is, one in the same direction as that of both A, and B, before collision.

If either body is immovable, it may be considered as infinite.

85. The reason of all these effects will be evident after a little consideration.—When a non-elastic body strikes another,

collision, have a common velocity; this, as in the case of non-elastic bodies [81], will be $\frac{AV+BV'}{A+B}$; and the velocity lost by A will be the difference between this common velocity and the original velocity of A; that is:—

$$v = V - \frac{AV+BV'}{A+B} = \frac{AV+BV-AV-BV'}{A+B} = \frac{BV-BV'}{A+B} = B \cdot \frac{V-V'}{A+B}$$

The velocity gained by B will be the common velocity, minus the original velocity of B; that is:—

$$v' = \frac{AV+BV'}{A+B} - V' = \frac{AV+BV'-AV'-BV'}{A+B} = \frac{AV-AV'}{A+B} = A \cdot \frac{V-V'}{A+B}$$

But, as the bodies are perfectly elastic, the effect is twice as great as if they were non-elastic—an additional and equal action being produced, by the return of the particles which were compressed, to their original shape. Consequently, the velocity lost by A, and that gained by B, will, each, be *twice* as great as if they were non-elastic. Hence the velocities of A and B, after impact, will be expressed, by twice the values which we have found, respectively, for v and v' in the above equations. Therefore, in reality,

$$v = V - 2B \cdot \frac{V-V'}{A+B} = \frac{2BV'+A-B}{A+B} V; \text{ and}$$

$$v' = V' + 2A \cdot \frac{V-V'}{A+B} = \frac{2AV-A-B}{A+B} V'$$

Since $v = V - 2B \frac{V-V'}{A+B}$, and $v' = V' + 2A \frac{V-V'}{A+B}$, it follows that

$$v - v' = V - V' - 2 \frac{B}{A+B} (V - V') = V - V' - 2 \frac{B}{A+B} (V - V') = - \frac{B}{A+B} (V - V') = \frac{B}{A+B} (V' - V)$$

—That is (changing all the signs) $V - V' = v' - v$; and $V + v = V' + v'$: or the sum of the velocities of one body, before, and after impact, is equal to the sum of the velocities of the other body before, and after impact—the velocity, gained by one body, being lost by the other. It is not to be supposed, however, that the velocity of each body, before and after impact, will be the same, the direction being merely changed; but that the velocity of one will be increased, and of the other decreased, to such an extent, as that they will have the same difference of motion, in the given direction. In the case of A being less than B, it would follow, that A has in some sense communicated to B more motion than it had itself—to the extent to which its own motion has become negative, or in the contrary direction.

which is immovable, the motion of the former is destroyed, in compressing the particles of both; and this motion is not restored, since the bodies, from the very nature of non-elasticity, remain compressed; and therefore cannot separate.

86. If a non-elastic body strikes another at rest, but movable, compression of the particles will go on, until the striking body has communicated to that which is struck, enough of force to set it in motion with some common velocity; one body then ceases to act on the other. But, since there is no force to cause their separation, they will move on together.

87. When both bodies are elastic, and one is immovable, compression proceeds, until half the motion is destroyed; the entire force—in an opposite direction—is then given back again to the movable body: on account of both bodies recovering their shape, with exactly the force which caused it to be altered.

88. Hence the effect of a moving body on a fixed plane, when both body and plane are elastic, is twice as great as when neither is so, the velocity and mass being constant; because the plane is then subjected, also, to the equal, and opposite force, restored by elasticity.

89. If one of the elastic bodies is in motion, and the other is at rest, but movable, when they are equal, compression goes on until a common velocity is acquired:—that is [81], until the body, at rest, takes away half its motion from the other; then, as the same effect is produced by the particles in recovering their former shape as in losing it, the body, originally at rest, receives all the remaining motion.

90. But if the striking body is larger than that which is struck, the whole motion of the former will not be expended in moving the latter; the former will, therefore, continue to move, though more slowly.

91. If the body that is struck is the larger, when the whole motion of the smaller will have been communicated, the larger will not have obtained a sufficient velocity to carry it away from the comparatively rapid reaction of the striking body; it partakes, therefore, to a certain extent, of the nature of an immovable body:—the effect is modified accordingly; and the smaller body rebounds from it.

92. If both bodies are in motion, in the same direction, that which is struck, will have its motion accelerated: and the impinging body will have its motion diminished—but to a less extent than before.

93. From what has been said, it may be anticipated that when a number of equal, and perfectly elastic bodies are placed in a right line, and in contact, if the outside one is made to impinge against that which is next it, only the other outside body will move, and with a force equal to that of impact. If

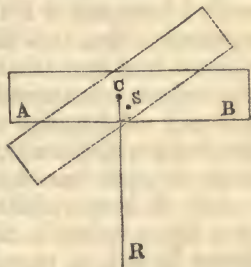
they are a decreasing series, they will all move; but with an increasing velocity. If they are an increasing series, the striking body, and the others in succession, except the last, will move backwards, and with decreasing velocity; but the last, or one most remote from impact, will move forward. In all these cases there are a number of actions and reactions, which, however simultaneous in appearance, are successive in reality.

94. THE CENTRE OF GRAVITY is that point, in any body, at each side of which there are equal momenta:—the smallness of the number of particles, at any one side, being compensated for, by their greater distance [43] from the centre of gravity—supposed to be the point about which they must revolve, if put in motion by the earth's attraction.—Hence the centre of gravity is that point which, being supported, the body will remain at rest.

95. If the point by which a body is suspended coincides with the centre of gravity, the body will remain at rest, in all positions; because, in every position, it will have equal and opposite momenta, at both sides of the point of support.

96. If a point S, fig. 6, *under* C, the centre of gravity, is supported, there will be “unstable” equilibrium—that is, equilibrium easily destroyed; because the least change will remove C from over its support; and, then, its tendency to assume the lowest possible position will not be counteracted.—For if the body turns ever so little round S, towards the position indicated by the dotted lines, the centre of gravity will be in the vertical line CR, and will be unsupported:—the body will, therefore, revolve.

FIG. 6.



97. When the point of suspension is *over* the centre of gravity, there will be “stable” equilibrium; because, the tendency of the centre of gravity to assume the lowest place, will bring the body, when disturbed, to its former position.

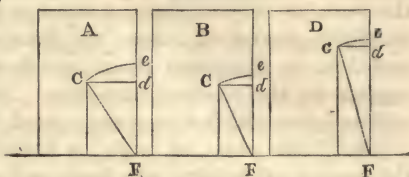
98. A line passing through the point of suspension, and perpendicular to the horizon, is called “*the line of direction* :” and the centre of gravity of the body will always be found, in some part of it.—For, when a body, suspended freely, is at rest, the centre of gravity must be supported; which cannot be the case unless it is directly under or over the point of suspension.

99. If a body is suspended, freely, from two different points in it, and the corresponding lines of direction are drawn, the centre of gravity must be found [98] in *both* these lines; and consequently, it must be, at the point of intersection. This, therefore, when the body is very thin, affords, sometimes, a means of discovering its centre of gravity.

100. If the line of direction falls *outside* the base of a body, the latter will overturn; for the centre of gravity, not being supported, motion must ensue.

101. If the line of direction falls *within* the base, the body will be supported, but the nearer it is to the extremity of the base, the more unstable the equilibrium; because the less the height through which the centre of gravity must be raised, in order that the body may be overturned.—This will be illustrated by fig. 7.

FIG. 7.

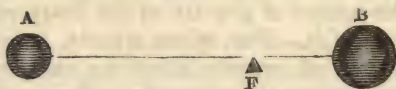


Let C be the centre of gravity of each of the bodies A, B, and D. To overturn any of them, the centre of gravity must describe the curve Ce, and must be lifted through the distance de—which is evidently increased, by removing the centre of gravity within the body, its height above the base being constant.

102. Raising the centre of gravity in the same line of direction renders it more easy to overturn the body. For the angle $d F C$, fig. 7, is diminished; and, therefore, in the right-angled triangled $d F C$, the hypothenuse and base approach to equality.—But, it is through the difference between the hypothenuse and base, that the centre of gravity must be raised, if the body is overturned. Hence, the danger of placing a large quantity of luggage on the top of a coach; hence, also, the accidents which occur, from persons suddenly standing up in a boat, through fear, &c.

103. It is very difficult to keep a body balanced on a point, or a line—unless a rapid rotary motion counteracts the tendency to fall, in one direction, by, after half a revolution, an equal tendency to fall, in the opposite, and these tendencies succeed each other so rapidly, that the body on account of its inertia, has not time [6] to yield to any one of them, before the next begins to operate.

104. If two bodies A and B, fig. 8, are immovably connected, by a rod supposed to be without weight, their common centre of gravity, when they are in equilibrio, will be at a distance from each,



inversely proportioned to its mass.”—For if one is twice as small as the other—to render its momentum equal to that of the other, we must make its velocity twice as great as that of the other [74].—But this is effected by removing it to twice as great a distance, from the centre of motion [43].

105. COMPOSITION, AND RESOLUTION OF FORCES.—When two,

or more forces, combine to produce a single one, they are said to be "compounded;" and that a single one is called the "resultant." When one force is decomposed into two, or more, it is said to be "resolved." Lines may be used to represent forces; because they may be drawn proportional to the forces, and in the same directions.

106. To find the resultant of any two forces.—"Cause the lines representing the forces—or lines proportional to them, and in the same directions—to form an angle, at the point

FIG. 9.

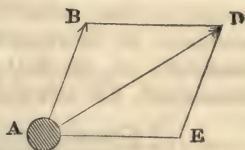
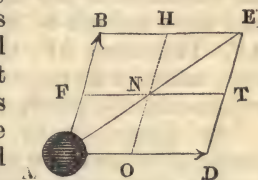
where they are supposed to act simultaneously; complete the parallelogram, and draw a diagonal between the lines representing the forces:—this diagonal will be the required resultant." For, let A, fig. 9, be the body on which forces AB and AD act.—Since there is a force acting on A, which, in a given time, would carry it across the line DE, or DE produced, and there is nothing to counteract that force, or any part of it—because there is no force in the opposite direction—the body *must* cross the line DE, or its prolongation. Again, since there is a force acting on the body A, which, in the same given time, would carry it across the line BE, or its prolongation, and there is nothing to destroy that force, or any part of it—there being no force in the opposite direction—the body *must* cross the line BE also, or its prolongation. That is, at the very same moment of time, it will cross both DE and BE; and therefore, at that same moment, it must be found at their intersection E. In a similar way we can prove that it must be found at any other point N, of the diagonal AE.—For, from the properties of similar triangles, of which there are four in the given figure (AFN, ABE, AON, ADE), AF, and AO are proportional to AB, and AD. Therefore, the body, for the reasons just given, must cross ON and FN, at the same time; and must, consequently, be found at their point of intersection N.

107. If the two forces are in opposite directions, and are equal, it is evident that their resultant will be 0: if they are unequal, it will be their difference. If they are in the same direction, it will be their sum.

108. When all the sides of any rectilinear figure, except one, are taken, "in succession," to represent the quantity, and direction of forces acting together, the remaining side, taken in an opposite direction, will represent the resultant.

FIG. 10.

Let the triangle ABD, fig. 10, be the given figure. Let AB and BD be the



The body is supposed to move from D to B, during the time it is passing from E to B; while, in reality, it will, in that time, have moved from H to B: since, but for centripetal force, it would be at H, instead of at B. But, since the arc, EB is supposed to be indefinitely small, the figures AEDB, and AEHB, may be considered equal, and coincident.

112. Centrifugal force may be illustrated by the apparatus represented, fig. 13.

When the handle H, is turned round, the pulley W, by means of the smaller pulley, P, moves the axis, DE, with considerable velocity:—DE carries round along with it, a thin hoop of brass, the upper side of which is capable of sliding freely upon it. When the hoop revolves with sufficient rapidity, centrifugal force causes it to assume the form indicated by the dotted lines—the spheroid it then generates, by rotation, being flattened at the poles, and bulged out at the equator. This instrument shows how the revolution of the earth, on its axis, causes it to be an oblate spheroid.* The equatorial diameter of the earth is about $26\frac{1}{2}$ miles greater than its polar. The equatorial diameter of Jupiter exceeds its polar, by 6,000 miles.

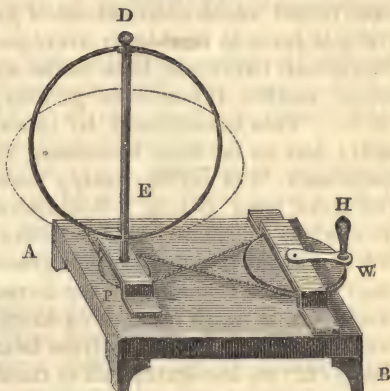
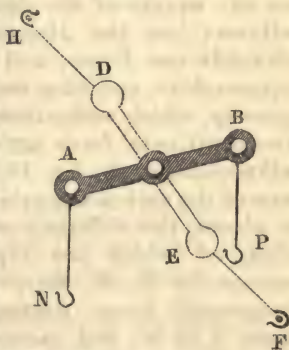


FIG. 13.

113. Centrifugal force is sometimes used to prevent accidents, during descent into mines.—The bar AB, fig. 14, is fixed on the axis which carries the drum, &c., to which the bucket is attached.

FIG. 14.

As long as the drum revolves, with moderate velocity, the hooks N and P, turning, respectively, on A and B, pass the pins H and F, without touching them. But, as soon as anything happens, which would cause the bucket to descend with dangerous rapidity, the hooks are thrown out, by centrifugal force; and being arrested by the pins, as represented by the dotted lines, the bucket is immediately prevented from descending further.

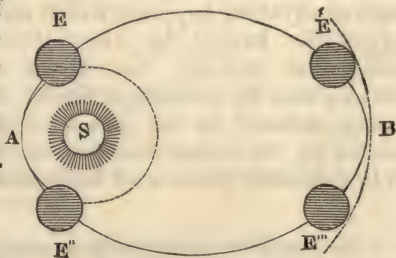


* The poles of an *oblate* spheroid are flattened, so that it resembles an orange; the poles of a *prolate* spheroid are prominent, so that it is like an egg.

114. Coaches, when passing quickly round a corner, are sometimes overturned, by centrifugal force. Men, horses, &c., running rapidly round a ring, counteract, instinctively, by leaning inwards, the tendency produced by centrifugal force.—From the position they assume, it becomes necessary, in order to overturn them, that their centre of gravity should be lifted through a greater height—since it is lowered; and also their line of direction falls on the base [101] at a point farther removed from that, round which their centre of gravity should turn:—but centrifugal force is unable to overcome the increased difficulty. In equestrian exercises, both horse and rider, when the motion is rapid, incline themselves greatly, towards the centre of the circle. This is supposed, by ignorant persons, to be a proof of skill; but so far from increasing the difficulty of remaining on horseback, it is indispensably necessary to prevent both horse and rider from falling. Sometimes the rider seems, merely, to lie against the horse, with nothing underneath to support him; but the rapid circular motion generates centrifugal force, sufficient to press him against the horse, so strongly, that the friction produced, is quite enough to keep him from sliding down. To prevent railway carriages from being upset, when passing round sharp curves, the outer rail is raised; this inclines the carriages inwards.

115. ELLIPTICAL MOTION.—When the centripetal and centrifugal forces have not a constant ratio, the motion produced is in some other figure than a circle. If the centripetal force varies directly as the distance, it will be an ellipse; the centripetal force will tend to the centre of the figure; and the body will, during revolution, twice approach to, and twice recede from, that which attracts it. If the centripetal force varies inversely as the square of the distance, the motion will, also, be in an ellipse; but the direction of the centripetal force will be towards one focus; and during revolution, the body will once approach to, and once recede from, that which attracts it. Since gravity, which varies inversely, as the square of the distance, is the centripetal force acting upon the planets, their orbits are ellipses.—Let S, fig. 15, be one of the foci of the orbit of a planet, the different positions of which are represented by E, E', &c.; the tangential force decreases from A to B; but increases from B to A. The effect of gravity is greatest at A:—but it cannot draw E to S, nor cause it to describe a

FIG. 15.



circle, since, on account of the velocity, the tangential force, also, is there greatest. Neither does the planet describe a larger curve at B; since the centripetal force, though diminished, has become at that point, *relatively* great.

116. Kepler found, from observation, that the orbits of the earth, and of all primary planets, are ellipses. Newton showed, from the nature of universal gravitation, and projectile motion, that the orbits, of both primary, and secondary planets must be ellipses.—Their paths are, however, disturbed by their mutual actions.

Two kinds of ellipse have been assigned:—that of Kepler and Newton, the common ellipse—in which the *sum*, and that of Cassini—in which the *product* of the two lines, drawn from the foci, to any part of the curve, is constant.

117. The greater the projectile force, the greater the eccentricity of the ellipse.—When the projectile force is very great, the curve will not return into itself; and the body will describe a parabola, &c. When the eccentricity is nothing, the curve described is a circle.

118. Centrifugal force is found, by “dividing half the radius into that height, from which the body must fall, to acquire—under the influence of gravity—the velocity of rotation per second; and multiplying the quotient, by the product of $32\frac{1}{6}$ and the weight of the body.”*

* Let t , be the time; and let v , be the velocity of projection. DB, fig. 16, an indefinitely small space in the tangent, which would be described, with a uniform velocity—will be [45] = $t v$. During this time, the body would recede from C—the centre of the circle—by a space=BO; since, by the action of the force of projection, it should have been at B, [111,] when, under the influence of centripetal force, it has been drawn to O:—but, as the arc is infinitely small, BO=DH. The effect of the centripetal force—since it is uniformly accelerating—

FIG. 16.

would be during the time $t[55] = \frac{Ft^2}{2}$; F being the last acquired velocity at the end of $1''$. We have seen, also, that the effect is BO or DH.—

Therefore, $\frac{Ft^2}{2} = DH$. But, from the nature of the circle, the triangles NDO and OHD are similar:—since they have a common angle; and the angles HOD (= ODB, an angle of the segment: for a small arc and its chord may be supposed coincident; and HO is drawn parallel to DB) and DNO are equal—because each is measured by half the arc DO.—Therefore $ND:DO :: DO:DH = \frac{DO^2}{ND} =$

(R being the radius of the circle) $\frac{DO^3}{2R}$. But the arc being very small, $DO =$

DB. Therefore $DH = \frac{DB^2}{2R}$ (because, as we have seen, $DB = t v$) $\frac{t^2 v^2}{2R}$. But

DH has been proved equal, also, to $\frac{Ft^2}{2}$. Therefore $\frac{2v^2}{2R} = \frac{Ft^2}{2}$. And $F = \frac{v^2}{R}$. Calling the velocity due to gravity in 1" (32½ feet) g ; v [57] = tg . Therefore

EXAMPLE.—A ball, weighing 15 lbs., and revolving in a circle 3 feet in diameter, makes 100 revolutions per minute, what is its centrifugal force? 100 revolutions per minute = $\frac{100}{60} = 1.66$, &c., revolutions per second. And since the circle is 3 feet in diameter, its circumference is $3 \times 3.141593 = 9.424779$ feet. Then, 9.424779×1.66 , &c. = 15.707965 feet, per second. But, a body, to acquire that velocity, must [56] fall 3.84 feet. And $\frac{3.84}{R} = \frac{3.84}{0.75} : \frac{3.84}{0.75} \times 32\frac{1}{6} \times 15 = 2470.4$ lbs.

119. It follows that, when the velocity and radius are constant, the centrifugal force is proportional to the weight.

120. When the radius is constant, the centrifugal force is directly proportional to the square of the velocity.

If the earth were to revolve seventeen times more rapidly than it does, the centrifugal force, at the equator, would be equal to gravity; and a body would not fall there, although unsupported. If the centrifugal force were still greater, the water, &c., on the surface of the earth, would be projected into infinite space; and there would be an impassable zone of sterility.

121. When the velocity is constant, the centrifugal force is inversely proportional to the radius.

122. When the number of revolutions is constant, the centrifugal force is directly proportional to the radius.

123. When the radius and centrifugal force are given, to find the velocity and number of revolutions per minute.—“Multiply the centrifugal force, corresponding to a unit of the weight, by the radius; and divide the product by $64\frac{1}{2}$:—this will give the height, from which the body must fall, to acquire the velocity required.* Having obtained this velocity [58], divide it into the circumference, and the quotient will be the time of one revolution:—dividing this quotient into 60, will give the number of revolutions per minute.”

EXAMPLE 1.—The weight of a body is 40 lbs.; its centrifugal

$v^2 = t^2 g^2 = t^2 g$ (twice the altitude due [55] to t'') multiplied by g . Calling $\frac{t^2 g}{2}$ (the altitude due to t'') a , we have $v^2 = ag$. And substituting this value of v^2 in the equation $F = \frac{v^2}{R}$, we have F (the centripetal force corresponding to a unit of the mass) = $\frac{2ag}{R} = \frac{ag}{\frac{R}{2}}$. Multiplying this by the weight, we have the centripetal force of the whole body—and therefore its equal, and opposite, the centrifugal.

* $F = \frac{2ag}{R}$ [118; note]. Therefore $FR = 2ag$; and $a = \frac{FR}{2g}$.

force is 1,874 lbs.; and the radius is 2 feet. Required the velocity, and number of revolutions. $\frac{1874}{40} = 46.85$ lbs. is the centrifugal force, corresponding to a unit of the weight. $\frac{46.85 \times 2}{64\frac{1}{2}} = 1.456$, is the altitude, corresponding to the required velocity. $\sqrt{2 \times 1.456 \times 32\frac{1}{2}} = 9.67$ is the velocity corresponding [58] to an altitude = 1.456, and also the required velocity. Then 12.56636 (the circumference) $\div 9.67 = 1.3''$ the time of one revolution. And $\frac{60}{1.3} = 46$, nearly, is the number of revolutions per minute.

EXAMPLE 2.—The radius is 3 feet; and the centrifugal force is equal to the weight; what are the velocity and number of revolutions? Since the centrifugal force and weight are equal, the amount of the former, corresponding to a unit of the latter is 1 lb.

But, $\frac{1 \times 3}{64\frac{1}{2}} = 0.0466$. And $\sqrt{2 \times 0.0466 \times 32\frac{1}{2}} = 1.73$, is the velocity. 18.849558 (the circumference) $\div 1.73 = 10.8957$. And $60 \div 10.8957 = 5\frac{1}{2}$, is the number of revolutions per minute

EXAMPLE 3.—Let the cohesive power of cast iron be 20 tons per square inch of section: what must be the velocity and number of revolutions, per minute, of a fly wheel, the diameter of which is 30 feet, the section 64 inches, and the weight of the cast-iron rim 25 tons: so that it shall burst asunder? The entire centrifugal force required will be $64 \times 20 = 1280$ tons. The centrifugal force corresponding to a unit of the weight will be $\frac{1280}{25} = 51.2$ tons = 114,688 lbs. $\frac{114688 \times 15}{64\frac{1}{2}} = 26741$ nearly. $\sqrt{2 \times 26741 \times 32\frac{1}{2}} = 1311.6$. 94.24779 (the circumference) $\div 1311.6 = 0.0718$. And $\frac{60}{0.0718} = 835.7$ revolutions.

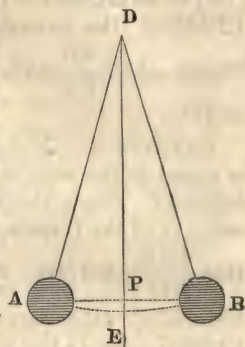
124. When the velocity, radius, and entire centrifugal force are given, to find the weight.—“Find the unit of centrifugal force, corresponding to the given velocity and radius [118]; and divide it into the entire centrifugal force.”

EXAMPLE.—A fly wheel 7 feet in diameter, making 20 revolutions per minute, has the same centrifugal force as one of 6 tons, 12 feet in diameter, and making 30 revolutions per minute: what is its weight? The centrifugal force of the latter fly wheel is [118] 795885.074422 lbs. nearly. The centrifugal force corresponding to a unit of the mass of the former is 15.352718 lbs., and $\frac{795885.074422}{15.352718} = 51840$ lbs., nearly; or 23 tons 2 cwt. 3 qrs. 12 lbs.

125. There are many examples of the application of centrifugal force to manufactures, &c.—By means of it, the flour is thrown from the rim of the revolving mill stone. It causes the air to pass, in a strong blast, from the vanes of the winnowing, and blowing machines. It is, as we shall see, the principle of the centrifugal pump, &c.

126. THE CONICAL PENDULUM consists of two balls A and B, fig. 17, attached, respectively, to the rods AD, and BD, turning on centres at D, and revolving on the axis DE.—They will describe a cone; and centrifugal force will cause them to fly asunder, when the time of one revolution = $\sqrt{DP \times 1.10784}$.^{*} Hence to find the length of DP, with pendulums intended to make a given number of revolutions, before they begin to fly asunder.—“Divide the time of one revolution by 1.10784; and the square of the quotient will be the length of DP in feet.”

FIG. 17.



EXAMPLE.—What must be the length of

^{*} The velocity of each ball will be the circumference of the base of the cone, multiplied by the number of revolutions per second:—or, which is the same thing, divided by the time of one revolution. That is, if t is the time of one revolution, and V , is the velocity—

$$V = \frac{2PA \times 3.141593}{t} \text{ and } V^2 = \frac{4PA^2 \times (3.141593)^2}{t^2}$$

But [118; note] the centrifugal force is equal to the square of the velocity divided by the radius. Therefore—calling the centrifugal force C —

$$C = \frac{4PA^2 \times (3.141593)^2}{t^2} \div PA.$$

But each of the balls is acted on by three forces—gravity, centrifugal force, and the tension of the rods; which may be represented, respectively, by DP, PA, and AD. Therefore,

Gravity:Centrifugal force::DP:PA. That is

Gravity:Centrifugal force::cos.ADP:sin. ADP—

or, in other words, as the vertical distance of the balls from D, is to their horizontal distance from P. Substituting for centrifugal force, its equal, we have—

Gravity: $\frac{4PA^2 \times (3.141593)^2}{t^2} \div PA$::DP:PA. Therefore, (multiplying the means

and extremes) gravity $\times PA = \frac{4PA^2 \times (3.141593)^2 \times DP}{t^2 \times PA}$. And $\frac{\text{gravity} \times t^2}{4 \times (3.141593)^2 PA} = \frac{DP}{PA}$. Therefore $t^2 = \frac{DP}{PA} \times \frac{4 \times (3.141593)^2 \times PA}{\text{gravity}} = \frac{DP \times 4 \times (3.141593)^2}{\text{gravity}}$

$\times 4 \times (3.141593)^2$. And $t = \frac{\sqrt{DP}}{\sqrt{\text{gravity}}} \times \sqrt{4 \times (3.141593)^2} = (\text{since gravity [55; note] is represented by } 32\frac{1}{2}) \frac{\sqrt{DP}}{\sqrt{32\frac{1}{2}}} \times \sqrt{4 \times (3.141593)^2} = \sqrt{DP} \times 1.10784$. That

is, the square root of the perpendicular distance DP, fig. 17, multiplied by 1.10784.

When ADP=45° centrifugal force=gravity; for DP=PA.

Since $t = \sqrt{DP} \times 1.10784$. $\sqrt{DP} = \frac{t}{1.10784}$; and $DP = \left(\frac{t}{1.10784}\right)^2$.—That is, the length of DP, for any number of revolutions, is equal to the square of the quotient, obtained by dividing 1.10784 into the time of one revolution.

DP, in feet, with pendulums intended to make 48 revolutions per minute, without flying asunder? The time of one revolution is $\frac{60}{48} = 1.25''$. And $\left(\frac{1.25}{1.10784}\right)^2 = 1.13$ feet = $13\frac{1}{2}$ inches nearly.

127. To find the number of revolutions, when DP is given.—“Multiply the square root of DP, in feet by 1.10784 :—the quotient will be the time of one revolution: divide 60 by this quotient, and the result will be the number of revolutions per minute.”*

EXAMPLE.—What number of revolutions will be made by pendulums, DP being 30 inches? 30 inches = 2.5 feet

$$\frac{60}{\sqrt{2.5 \times 1.10784}} = 34 \text{ revolutions, nearly.}$$

128. Since 1.10784 is invariable, “the periodic time is proportional to the square root of DP.”

EXAMPLE.—When DP=30 inches, the number of revolutions is 34; what will the number be, when it = 24?—When

DP=30, the periodic time is $\frac{60}{34} = 1.76$. Then $\sqrt{30} : \sqrt{24} :: 1.76 :$

$\frac{\sqrt{24} + 1.76}{\sqrt{30}} = 1.574$, is the time of one revolution, when DP=24.

And $\frac{60}{1.574} = 38$, nearly, is the number of revolutions per minute.

As the balls diverge, the \sqrt{DP} decreases; hence, to produce further divergence, the velocity of rotation must be increased.

129. Bodies have a tendency, when revolving, to turn round on their shorter axis—which, therefore, will sometimes assume a certain position in opposition to gravity.

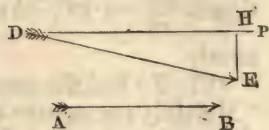
130. When bodies revolve, it must be about their common centre of gravity; for we may suppose that the centripetal force is derived from, and its quantity influenced by, the distance from this point:—besides there would not otherwise, be equal and opposite momenta at all opposite sides, and the centre of gravity could not retain its position.

131. If two bodies revolve about a third, it is, in reality, their common centre of gravity that revolves; because it is at that point the force of projection may be supposed to be concentrated. The centre of gravity of the earth and moon is 6,000 miles from the former:—hence the earth is 12,000 miles nearer to the sun at full, than at new moon. The centre of gravity of the sun, earth, and moon is within the sun.—The sun moves round this common centre of gravity.

* We have seen [125; note] that $t = \sqrt{DP} \times 1.10784$. But $\frac{60}{t} = \frac{60}{\sqrt{DP} \times 1.10784}$ is the number per minute.

132. To find how much of any force DE, fig. 18, is efficient, in a given direction AB. "From the commencement D, of the line representing the given force, draw DP parallel to the direction of the required force; and from E, the extremity of the line representing the given force, draw EH perpendicular to DP:—DH will represent the amount of the force DE, which is efficient, in the direction AB.

FIG. 18.



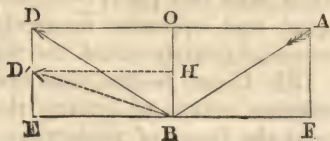
133. Should the perpendicular fall on DP, produced *backwards* from D, the given force, is not only inefficient in the required direction, but contains a force exactly opposite to it.

134. The perpendicular HE represents a force, wholly without effect in the required direction—since it cannot be so resolved as to produce a force, either in the same direction, or in the opposite. To render DH effective, HE must be destroyed, by an equal and opposite force.—“Resolution, therefore, is reducible to ‘composition’ of forces:” since we may suppose two forces DE, and EH (the force which neutralizes HE) to produce [106] DH, as their resultant. And the real question is not what part of DE is effective, in the direction AB; but what force, along with DE, would produce a force in that direction.

135. It is evidently, more economical to use a single force than the resultant of two or more:—for the resultant can never be equal to the sum of the forces which produce it; since, however many the sides of the rectilinear figure [108] representing the forces employed, only one of them can represent the resultant.

136. The laws, which govern the composition and resolution of forces, enable us to show that a body, striking a plane, will be reflected from it, at an angle depending on the amount and direction of the original force; and on the elasticity of the plane, and of the body.—Let AB, fig. 19,

FIG. 19.



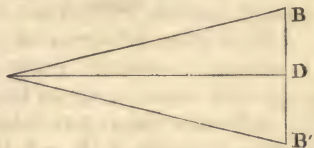
represent the quantity and direction of the force, with which a body impinges against the plane EF. Let this force be resolved into AO parallel, and OB, perpendicular to EF. When the body reaches the plane, it will be acted upon by two forces, one represented by BE=AO; and the other—if the plane is perfectly elastic—by BO=OB:—or, if it is not perfectly elastic, by some force BH, less than OB. The resultant of BE and BO will be BD=BA; and making the angle of reflexion DBE=the angle of incidence ABF.—The resultant of BE and BH would be BD', less than BD; and the angle of reflexion D'BE, would be less than the angle of incidence ABF.—Some writers con-

sider ABO and DBO as the angles of incidence and reflexion: they also are equal, being the complements of equal angles.

137. These principles show the importance, which should be attached to the "line of draft," in vehicles; and that its direction must be, theoretically, such as will cause the pull to be parallel with the intended motion.—Let the direction, in which the force is applied be represented by AB, fig. 20; the intended direction of the body being AD. AB may be resolved

FIG. 20.

[132] into AD—which is in the required direction, and DB—which is expended in lifting the load. We shall find, hereafter, that a certain quantity of force, in the direction DB, is not useless.

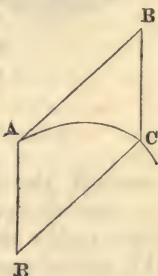


138. If the pull is in the direction AB', it is resolvable into AD—in the direction of the intended motion, and DB'—which depresses the load, and, therefore, increases its pressure, and, by consequence, the draft.

139. The path of a projectile is a parabola.*—Let a body be projected from A, fig. 21, with a force that,

FIG. 21.

in a given time, would carry it to B; while, in the same time, it would fall, under the influence of gravity, from B to C. AB (since it represents a uniform force—that of projection [45], $\propto t$; and $AB^2 \propto t^2$. But [50] BC since it represents gravity) $\propto t^2$.—Therefore $BC \propto AB^2$. And, since $BC = AR$; and $AB = RC$, $AR \propto RC^2$. That is, the abscissa varies as the square of the ordinate—which is found to be the property of the parabola.



140. The calculated, and the actual path of a projectile are, on account of the resistance of the air, extremely different.—A musket ball, having an initial velocity of 1,700 feet per second, has an actual range of only about half a mile; while, by calculation, it should have a range of 17 miles. When the velocity is more than about 1,340 feet per second, the air cannot rush in behind with sufficient rapidity; which causes a partial vacuum:—and thus adds a resistance of near 15 lbs. to the square inch. A ball 36 lbs. weight, and $6\frac{1}{2}$ inches in diameter, moving 1,600 feet per second, meets with a resistance, from the air of about

* A parabola is one of the five conic sections—which are, the *triangle*, formed by the outline of a section, passing through the vertex and any part of the base; the *circle*, by the outline of a section, parallel to the base; the *parabola* of a section, parallel to the side; the *ellipse* of an oblique section, through both sides; and the *hyperbola*, of a section making a greater angle with the base, than the side.

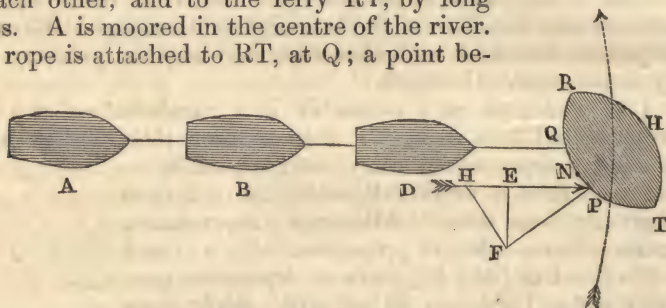
The triangle and circle are not, generally, considered as conic sections.

417 lbs. Adding to this $478\frac{1}{2}$ lbs. the resistance arising from the partial vacuum behind, we shall find that the total resistance is nearly 900 lbs.

141. There are many examples, both of the composition, and resolution of forces, besides those already noticed. The united action of two forces, the one tending to draw the water from the poles to the equator, the other to carry it from east to west—on account of its having a less velocity than the parts of the earth over which it passes—must necessarily produce a tidal current in an intermediate direction [18].

142. Flying bridges, so common on the rapid rivers of the Continent, consist of boats moved by the stream; and afford a very convenient mode of bringing passengers, horses, carriages, &c., across without any labour, on the part of the boatmen. A number of boats A, B and D, fig. 22, are united to each other, and to the ferry RT, by long ropes. A is moored in the centre of the river. The rope is attached to RT, at Q; a point be-

FIG. 22.



tween N, the centre of the side, and R one end. The force of the stream, represented by HP, is resolved into FP, perpendicular to the side of the boat—consequently [76] effective; and HF, at right angles to FP. FP is resolved into FE, which brings the boat, from one bank, to the other, and EN at right angles to FE. When the rope Q, is moved to a point between N and T, the boat crosses the stream in the opposite direction. The Po is passed in this way near Rovigo, with great facility.

143. A boat drawn by horses, along a canal, is an example of the composition of forces.—The current acting on the rudder, and the draft of the horses, producing a resulting motion along the canal.

144. SOURCES WHENCE FORCE IS GENERALLY DERIVED.—We obtain force from water, air, steam, animal strength, &c. Water, and steam, will be considered hereafter.

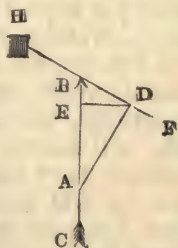
We obtain force from air, by the windmill, or some analogous means. The windmill is used, very extensively, in Holland, to work pumps for drainage—a large portion of the country being under the level of the sea. The sails may be variously arranged:—those which are attached to arms, lying in a vertical

plane, are the most common. The full effect of the sails is produced, when the plane of the arms, which carry them, is perpendicular to the direction of the wind. This position is secured by various contrivances:—sometimes by a lever; at others by a *wind vane*, fixed to the movable cap of the mill, but projecting some distance from it, on the side opposite to that, at which the sails are placed—the plane of the vane being perpendicular to that of the arms. The vane is moved by the wind, whenever it blows in any direction, except that which is perpendicular to the great sails; and by revolving, works a pinion, which carries the movable cap round on the mill-house, until the plane of the sails is perpendicular to the direction of the wind—which has then no action whatever on the vane. The angle made by the plane of each sail with the plane in which the arms lie, is of great importance; and has formed the subject of much inquiry. If the wind were to act perpendicularly on, or parallel to, the plane of the sail, the latter would have no tendency to revolve.—The plane of the sail must, therefore, occupy some intermediate position. This position—or the angle made by the plane of the sail with the direction of the wind—is called the “weather of the sail.”—It is greatest near the centre of motion; for the greater the velocity of a given part of the sail, the less the effect, which the wind has on it—since the smaller the difference between their speeds, hence, we are obliged to increase the action of the wind on the distant parts of the sail, which, on account of their greater velocity, withdraw themselves, as it were, from its influence.—This is effected by causing the wind to act, in a direction nearer to the perpendicular. The angle of weather, for any part of the sail, is found by the following formula of Maclaurin— a being the velocity of the wind; and c that of any given part of the sail; the effect of the wind on that part will be a maximum, when “the tangent of the angle of the winds’ incidence, or the sails’ inclination to the axis, is to the radius, as $\frac{\sqrt{2+9c^2}}{4a^2}$, is to 1.” There are, in Ireland, undoubtedly, many

places, where windmills might be used with as much advantage as in other countries; and they may be constructed on the small scale, at a trifling expense.

145. The action of the wind, on the sail of a windmill, may be understood from fig. 23.—Let its direction and amount be represented by CB; let HF be a section of the sail, and of the arm which carries it. AB may be resolved into AD perpendicular to the plane of the sail—and therefore effective, and DB parallel to it—and

FIG. 23.

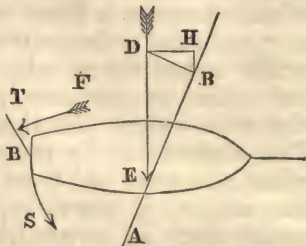


therefore entirely without effect. Since AD is not tangential, all of it is not effective in producing rotary motion [111]; and it is to be resolved, into ED, tangential, and AE, at right angles, to ED. If, therefore, AB represents the force of the wind, ED will represent the part of it, which causes the sails to revolve.

146. The wind DE, fig. 24, acting on the sail of a ship, will impel it in any direction DH, not exactly opposite to that of its own motion.—DE may be resolved into

FIG. 24.

DB, perpendicular to the plane of the sail—and therefore effective; and, BE parallel to the plane of the sail—and ineffective. DB may be resolved into DH, which is in the direction of motion—and therefore effective; and HB, perpendicular to DH, and tending merely to move the vessel round—but counteracted by the stream, flowing along the side, and acting on the rudder.



147. A vessel will not steer, unless its velocity is sufficient to produce a current against the rudder.—Hence, even in storms, it is necessary to keep up *some* sail, or the ship would not be under command. And when a steamer, going down the Rhone, Rhine, and other rapid rivers, stops at the different towns along the banks, the bow is turned *up* the stream; that, when starting, the current, striking on the helm, may render the vessel manageable.—Without this, it would drift down the stream, until it should acquire a certain velocity.

148. Animals produce very different effects, in different circumstances. The greater their velocity, the less resistance they can overcome; and *vice versa*. Their motion may be so rapid, that they will be able to carry only themselves; or they may move so slowly, that no work will be done. The useful effect lies between these extremes. Animals work best, when their efforts are not constantly the same; also, when they are allowed to rest occasionally.

149. It is calculated that a man will walk, unburdened, $4\frac{3}{4}$ feet per second (or about $3\frac{1}{4}$ miles per hour) for 10 hours per day.—Taking his weight at 140 lbs. he will have carried 23,940,000 lbs. a distance of 1 foot. He will carry $85\frac{1}{2}$ lbs. on his shoulders $2\frac{1}{3}$ feet per second, for 7 hours per day.—This, neglecting his own weight, will be 4,740,120 lbs. carried 1 foot. He will ascend steps, unburdened, at the rate of $\frac{12}{5}$ feet per second, for 8 hours per day.—Taking his own weight at 140 lbs. he will have raised 1,935,360 lbs. 1 foot high; or about the $\frac{1}{2}$ th part of what he carried on a horizontal plane. A man has been found to lift about 1,224,000 lbs. 1 foot high, in a day,

working on the whole, for 5 hours; but working, and resting alternately.

150. A horse, walking at the rate of about $3\frac{1}{2}$ feet per second, will carry 256 lbs. for 10 hours per day. That is, neglecting his own weight, 32,256,000 lbs. carried 1 foot; or about six times as much as a man, doing the same kind of work. Moving with double the velocity, he will carry 171 lbs. for 7 hours per day:—which is, 30,164,400 lbs. carried 1 foot. A horse that will carry 864 lbs., will draw with a force, equal only the $\frac{1}{6}$ th part of that weight. In examining the amount of animal power, we can, of course, obtain only approximations:—for, different men, &c., will perform different quantities of the same kind of work; and those who are used to it, will do more than those who are not.

151. The effects produced, vary with the kind of work.—According to Buchanan, the exertions of a man in working a pump, turning a winch, ringing a bell, and rowing a boat, are as the numbers 100, 167, 227, and 248.

CHAPTER II.

The Mechanical Powers, 152.—The Lever, 156.—Application of the Lever to the Measurement of Weight, &c., 162.—Combinations of Levers, 177.—The Pulley, 178.—Combinations of Pulleys, 181.—The Wheel and Axle, 191.—The Differential Axle, 192.—Examples of the Wheel and Axle, 194.—Combinations of Wheels and Axles, 196.—Different kinds of Wheels, 201.—Teeth of Wheels, 208.—The Inclined Plane, 224.—Descent of Bodies down Planes, and Curves, 230.—The Wedge, 237.—The Screw, 241.—Application of the Screw to various purposes, 245.

152. THE MECHANICAL POWERS.—There are two ways, in which the momentum, which is at our own disposal, may be altered, by the modification of its elements.—We may change the relative amounts of the velocity, and the mass [74] either by increasing the former, and diminishing the latter: or by diminishing the former, and increasing the latter. This change is effected by what are called “the mechanical powers.” Since the momentum itself is not altered, we can, at once, compute the effect of these powers, or of any combination of them, however complicated, if we know the *relative* velocity of the power and weight. For, “the power, multiplied by its velocity, is equal to the resistance, multiplied by its velocity.” This, which is called the principle of *virtual velocities*, is one that should never be lost sight of, in mechanics. Were it always remembered, much time, vainly expended by ingenious persons, in seeking for what is called the “perpetual motion,” would be saved:—since, the province of machinery is not to *create* momentum, but to *modify* its elements. And were it possible to construct an infinitely perfect machine, we should receive from it, only that amount of motion which we imparted to it.—But the very best, we can form, consumes *some* power: and the amount, destroyed, is dependent, in a great degree, on its complication. We are to conclude, therefore, that machinery should never be used, except where it cannot be avoided; and that, when used, it should be as simple as possible.

153. To exemplify the principle of virtual velocities, let us suppose that, with a certain machine, the resistance moves through 100 times less space than the power.—The momentum of both being equal, the mass of the former must be 100 times the mass of the latter.

154. Whatever causes motion is called a *power*, or *prime mover*. The power may be considered, as so many pounds, *falling* through a certain space; and the resistance, or work to

be done, as so many pounds, *to be raised* through a certain space. We shall designate the power, by P ; the resistance—or weight by W ; and the fulcrum*—or point of support, by F .

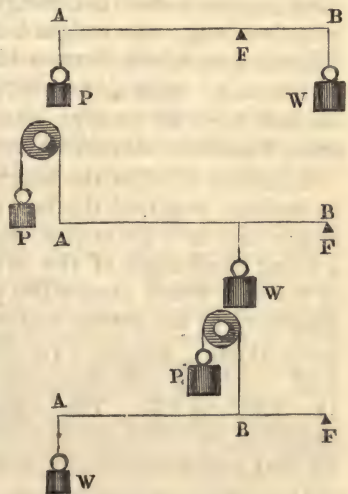
155. There are six mechanical powers, reducible to two:—the *lever*—which being modified, gives rise to the *pulley*, and the *wheel and axle*; and the *inclined plane*—from which are derived, the *wedge*, and the *screw*. The laws which govern the lever, and the inclined plane, being well understood, those belonging to the rest, are comprehended without difficulty.

156. THE LEVER is an inflexible rod, supposed to be without weight. It is of two kinds:—that with equal, and that with unequal arms. The latter may be subdivided into that which has the fulcrum, between the power and weight; and that which has the fulcrum at one end—the power, or weight, being at the other. A lever “of the first order,”—or that which has the fulcrum between the power and weight—may be used to increase either the mass, or the velocity, of the weight. A lever “of the second order”—or that which has the fulcrum, at one end, the power being at the other—can increase only the mass of the weight. And a lever “of the third order”—or that which has the fulcrum at one end, the weight being at the other—can increase only the velocity of the weight.

157. The lever with equal arms alters neither mass, nor velocity; but it enables us to change the direction, at which the power acts.

158. Whatever may be the kind of lever, “the power and weight are inversely proportional to the lengths of the arms connected with them.”—For, calling the velocity of the power V ; and that of the weight V' . $PV = WV'$. But, as the velocities of the power, and weight, are proportional to the spaces, which would be described by them—were they put in motion; and [43] these spaces are proportional, to the distances of the power and weight from F , fig. 25, the centre of motion; we may substitute these distances for V , and V' ; and the above equation then becomes $P \times AF = W \times BF$. That is, the power multiplied by the length of the arm which carries it, is equal to

FIG. 25.



* *Fulcrum*, a prop. *Latin*.

the weight multiplied by the length of the arm which carries it. And, forming this equation into a proportion, $P:W::BF:AF$.

159. Hence, for example with a lever, having the arm, which is connected with the power, seven times as long as that, which is connected with the weight; the mass of the weight, will be seven times as great as the mass of the power:—but the power will move through seven times as much space.

160 The velocity, or mass, of the power, or weight, may be found from the above equation.

EXAMPLE 1.—Let $P=50$; $W=472$; and, the velocity of the weight=3. What must be the velocity of the power, to produce equilibrium?

$$P \times AF = W \times BF. \text{ Therefore}$$

$$AF = \frac{W \times BF}{P}; \text{ and, substituting the given values,}$$

$$AF, \text{ or the velocity of the power} = \frac{472 \times 3}{50} = \frac{1416}{50} = 28.32.$$

EXAMPLE 2.—Required the weight which, at 7 feet from the fulcrum, will balance 8756 lbs., at 4 feet from it.

$$P \times AF = W \times BF. \text{ Therefore}$$

$$P = \frac{W \times BF}{AF}: \text{ and substituting the given values, } P = \frac{8756 \times 4}{7} = 5003.4286.$$

EXAMPLE 3.—What must be the respective lengths of arms, carrying the power and weight, with a lever of the first order 5.73 feet long; the weight being 84 lbs., and the power 23 lbs.? Call the arm which carries the weight x ; the other will then be $5.73 - x$. And $x \times 84 = 5.73 - x \times 23$. Solving this equation, we find $x = 1.23$ nearly; and $5.73 - x = 5.73 - 1.23 = 4.5$.—The arms, therefore, should be, respectively, 4.5, and 1.23.

EXAMPLE 4.—Let the length of a lever, of the first order, be 14 inches; required the lengths of the arms, so that, while the power moves 1.75 inches, the weight may move 4.32 inches? x being the length of the arm which carries the weight; that of the arm which carries the power will be $14 - x$. The spaces described by the power and weight are [158] as the arms which carry them. Hence $1.75:4.32::14-x:x$ and $1.75x = 14 - x \times 4.32$. Solving this equation, we find $x = 9.963$; and $14 - x = 14 - 9.963 = 4.037$. The respective lengths of the arms must, therefore, be 9.963, for that which carries the weight; and 4.037, for that which carries the power.

161. It is not necessary that the arms of the lever should be in a right line.—They may, as in fig. 26, form an angle, when the directions in which the power and weight act, are not parallel.

This species of lever follows the same law as the rectilinear.—For, rotation round F, is the effect to be produced; and, of the two forces required for this purpose [111], the centripetal is supplied, by the lever itself, and the tangential, by the power:—the result is the same, whatever may be the radii, to which the directions of the power, and weight, are, respectively, perpendicular, and attached—provided these radii are immovably connected.

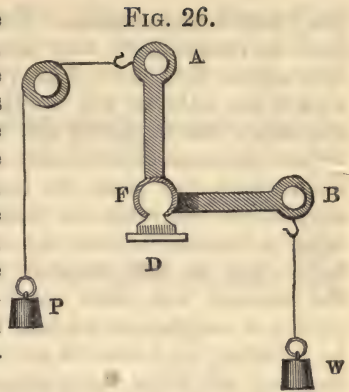


FIG. 26.

Neither is it necessary that the arms should move in the same plane:—thus they may be A and B, fig. 27, moving round along with the rod DE, which turns on centres D and E.

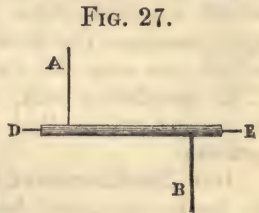


FIG. 27.

162. APPLICATION OF THE LEVER TO THE MEASUREMENT OF WEIGHT.—*The ordinary scales*, for weighing merchandize, is an example of the lever with equal arms.—For, since the power and weight are intended to be equal, the arms also [74] must be equal. We can ascertain, whether or not, the arms are of the same length, by accurately counterpoising two bodies in the scales, to be tested, and then changing them from one scale to the other. If equilibrium still remains, the arms are equal—since, it is evident, that the power, multiplied by the length of either arm, will be equal to the weight, multiplied by the other.

163. If the arms are not equal, the real weight of any body may be found, by weighing it in each scale, multiplying together the weights thus obtained, and taking the square root of the product.*

164. The position of the point of suspension, in a balance, is a matter of importance.—It may be under, over, or coincident with the centre of gravity of the beam. If it *coincides* with it, the weights in the scales may be equal, and yet the beam [95] may not be horizontal:—which would be inconvenient, as it is from the horizontality of the beam we judge that the weight, and the substance to be weighed, are equal. If it is *under* the centre of gravity, the equilibrium, obtained with equal weights,

* For, let a represent the article to be weighed; let b and c be the unequal arms of the balance; let x be the weight of the body, when suspended from c ; and y , its weight, when suspended from b .—In the former case, from the nature of the lever, we have $a \times b = x \times c$ and in the latter, $a \times c = y \times b$. Multiplying the corresponding terms in the two equations, we get $a^2 bc = xybc$; then, dividing both by bc , $a^2 = xy$; and $a = \sqrt{xy}$.

[96] would be unstable. The point of suspension must, therefore, be immediately *over* the centre of gravity of the beam.—The nearer the centre of gravity is to the point of suspension the slower the balance will oscillate; since gravity will be the less effective; but it will be the more easy to put it in motion.—Hence slowness of oscillation is a proof of delicacy. If the points, from which the pans are suspended, are above the centre of suspension, the more the balance is loaded, the more its sensibility is increased, since the centre of gravity is raised—but the latter may, at last, coincide with the point of suspension, and the balance will, then, cease to act. If they are below the centre of suspension, adding weights diminishes the sensibility, by lowering the centre of gravity. The balance is independent of the load, when the three points of suspension are in a right line, which is a little above the centre of gravity. Loading the scales then increases the sensibility, by raising the centre of gravity—which can never be quite so high as the centre of suspension. The sensibility will, however, be decreased by friction, to the same extent, that it is increased by raising the centre of gravity.

165. The fulcrum of a balance should be as thin as possible:—in well-constructed balances, it is a knife-edge, of hard steel, playing on agate; and raised up, when not in use—lest its sharpness should be impaired. If the fulcrum is not thin, the arms of the balance are not always equal in length.—Let AB

FIG. 28.

fig. 28, be a lever, resting on a thick fulcrum E; the arms being equal. If it assumes the position A'B', there will be a difference between the lengths of the arms, equal to the width of E. In the position A''B'' the arms are also unequal, to the same extent.



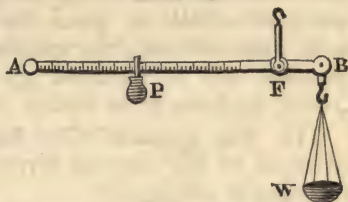
166. The greater the angle through which a balance moves, with a given weight, the more sensitive it is. Lengthening the beam increases the sensitiveness, by causing the preponderating weight to act with a greater leverage.

167. In philosophical experiments, the weights should be as accurate as possible; and, to prevent them from being altered, by corrosion, the smaller ones, at least, ought to be made of platinum.—They should be moved from one place to another with a forceps, that they may not be affected, either by moisture, or change of temperature. Troy weight is generally used; as there is an exact number of grains in the troy ounce. When the barometer stands at 30 inches, a cubic inch of distilled water, having a temperature of 62°, weighs 252.458 grains.

168. *The Steel Yard*, fig. 29—sometimes called, from a mis-

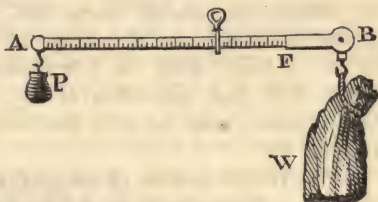
conception—the “Roman* balance,” has the fulcrum F , and the hook to which the scale, &c., containing the substance to be weighed, is attached, fixed permanently. The weight P , is movable; and, according to its place—ascertained by a graduated scale—the arm which carries it is practically, longer, or shorter. The two arms AF and BF , being counterbalanced, may be considered without weight.

FIG. 29.



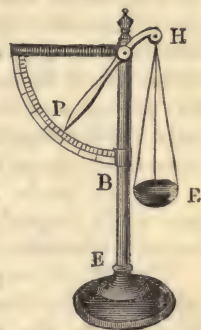
169. *The Danish Balance*, fig. 30, differs from the steel yard, by having the points, to which the weight and counterpoise are attached, fixed—the fulcrum F being movable, so as to alter the relative lengths of the arms.

FIG. 30.



170. *The bent lever balance*, fig. 31, is so contrived that, the fulcrum, counterpoise, &c., remaining the same, the amounts of very different weights may be ascertained.—Its action depends on the fact that, in proportion as H is depressed, by loading the scale E , the leverage of the counterpoise P —which also acts as an index—and, consequently, its efficiency is increased. The weight of a body in E is shown on the graduated arc AB , by P .

FIG. 31.



171. *The Nut-cracker*, fig. 32, is an example of the lever, which has the power at one extremity A , and the fulcrum F , at the other: the resistance W , being between B both.

FIG. 32.



172. *The human arm*, fig. 33, is an example of the lever, having the power between the fulcrum and resistance. NP is the muscle, acting at P ; the elbow F , is the fulcrum, and the weight W , is supported by the fingers. The seeming incon-

* Its name is said by some to be derived from *Romman*, an eastern word, signifying the pomegranate; and to have been suggested by the shape of the weight employed.—I have, however, seen this kind of balance used more commonly in Rome than in any other place.

venience of such a lever, is more than counterbalanced, by the compactness which it gives to the arm; and, although the muscle, on account of it, requires greater power, no force is, in reality, lost.

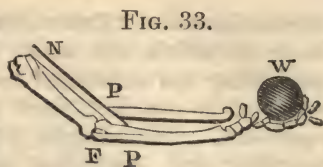


FIG. 33.

173. The common *claw hammer*, used to draw nails, is an example of the angular lever. Also, the *bell-crank* [161]—so common in machinery.

Many other instances of the application of the lever, to useful purposes, will suggest themselves.

174. When the power and weight, or either of them, does not act perpendicularly, on the arms of the lever, $P:W::FD$, (a perpendicular to BW , the direction of W): FH (a perpendicular to AP , the direction of P)*.

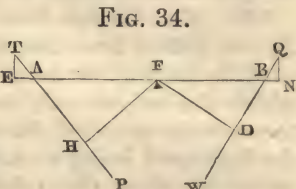


FIG. 34.

175. If the power, or weight, does not act perpendicularly to the arm which carries it, it becomes less effective:—but no force is lost, since the space, described by the power, or weight, is proportionably diminished. Thus, were the power to act perpendicularly to AF , fig. 34, it would be more effective, but more force would be consumed, since the space described would be the arc of a circle the radius of which is AF . When the power acts perpendicularly to FH it is less effective; but less force is consumed, since the space described by the power is the arc of a smaller circle, the radius of which is FH .—Many mistakes are made regarding the *crank*—a species of lever we shall examine hereafter—from this fact not being well understood.

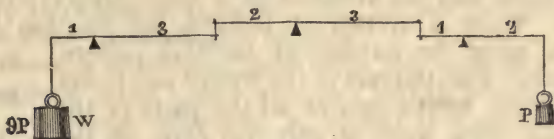
176. With every kind of lever “the power, multiplied by a perpendicular from the fulcrum to the direction of the power, is equal to the weight, multiplied by a perpendicular to the direction of the weight.”—When the power, and weight, act perpendicularly to the arms which carry them, the arms themselves are “perpendiculars” to their directions.

177. COMBINATIONS OF LEVERS.—With a system of levers like that represented, fig. 35, there is equilibrium, when “the power multiplied by the product of the alternate arms—beginning

* For, produce AP to T . Let TA represent the quantity and direction of the power; and resolve it into TE , tangential to AF —and therefore effective, and EA , parallel to AF —consequently ineffective. In the same manner, produce BW to Q ; and resolve QB , representing the quantity and direction of the weight, into QN , effective, and NB , ineffective. Then [158] $AF \times TE = BF \times QN$. But, as the triangles TEA and FHA , QNB and FDB are similar. $TA:AF::TE:FH$. Therefore $TA \times FH = AF \times TE$. And $QB:BF::QN:FD$. Therefore $QB \times FD = BF \times QN$. But, as there is supposed to be equilibrium— $AF \times TE$ (the effective part of the power) = $BF \times QN$ (the effective part of the weight). Hence $TA \times FH = QB \times FD$. And $TA:QB::FD:FH$.

with that which is next the power, is equal to the weight, multiplied by the product of the remaining arms.—For, the velocity of the power, compared with that of the weight, is increased in the same proportion, as the product of the alternate arms,

FIG. 35.



beginning with that next the power, is rendered greater than the product of the remaining arms.—Thus, the resistance, belonging to the first lever (which is the power of the second), $= 2P$; since the arm which carries it is twice as long as the other. The resistance, belonging to the second lever (which is the power of the third) $= 3P$, since the arms are as $3:2$. The resistance, belonging to the third lever, is equal to three times its power; since one of its arms is three times as long as the other.—That is, $W \times 1 \times 2 \times 1 = P \times 2 \times 3 \times 3$: or $W = 9P$.

178. THE PULLEY is a circular disc, turning on its centre, and carrying a cord, or chain, in a groove on its circumference. The case, in which the disc turns, is often called a *block*, and the disc, or pulley itself, a *sheaf*.—A single block may contain many sheaves. In our calculations, we shall consider each disc as a pulley; since its effect is not altered, by its being in a separate block, or not.

FIG. 36.

179. The pulley is a modification of the lever with equal arms—being a system of levers, of which only one of them, AFB , or $A'F'B'$, fig. 36, acts at a time; and all of them have a common fulcrum. Its action, therefore, is the same as that of the rectilinear, or the angular lever: but it has this advantage over it, that the power, and weight, are always perpendicular to the arms which carry them. The levers come, successively, into action, without any interruption.

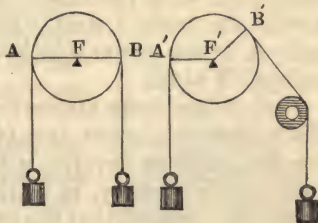


FIG. 37.

180. A pulley is either *fixed* or *movable*. A fixed pulley, fig. 36, does not increase either the mass, or the velocity of the weight; but it is often very useful, in changing the direction of the force. A movable pulley, FB , fig. 37, having one extremity of the cord fixed at P , and the power acting at S , may be considered as a



lever of the second order—having the fulcrum at F, the weight at A, and the power at B.

181. COMBINATIONS OF PULLEYS.—A system of pulleys may be divided into that which has but one cord, and that which has more than one. When the latter is used, the extremities of the cords may be attached to a fixed support; or to the weight. When a system of pulleys, fig. 38, has but one cord, n , being the number of movable pulleys, $W = P \times 2n$. For the sum of the weight and power is supported, by the sum of all the parts of the cord: but, since there is only one cord, all the parts must have the same tension:—or, in other words, each part must support the same amount of the sum of the power and weight. In this case, the cord is divided into three parts, therefore,

each part sustains $\frac{P + W}{3}$; and, as two of them sustain the weight; and the remaining one the power—

$$W = 2 \times \frac{P + W}{3} \text{ and } P = \frac{P + W}{3}$$

Therefore, $P : W :: \frac{P + W}{3} : 2 \times \frac{P + W}{3} :: 1 : 2$. That is, the weight is equal to the power, multiplied by $2n$. The same reasoning would hold, with any number of movable pulleys.

182. Fig. 39 represents a combination of pulleys in which the sheaves of each block are not all on the same axis.—But the mode of calculating the effect is still the same. And, since there are but two pulleys, in the lower block—that is, two movable pulleys, $W = 4P$.

183. When there are several sheaves, in the same block, there is a great loss of power, from friction. For the sheaves revolve with unequal velocities: each having to carry, in addition to the cord which runs from itself, all that has run off from the preceding ones. The wear and tear, also, is very unequal. If we examine the quantity of cord that is carried off, by each pulley, we shall find, that the velocities of the movable pulleys are as 1, 3, 5, &c.; and of the fixed as 2, 4, 6, &c.—or, with reference to themselves only, as 1, 2, 3, &c. If the sheaves are all of the same diameter; and the weight is raised through a space, equal to the semi-circumference of one of them; a portion, equal in length to half that semi-circumference, will have rolled off the first movable pulley, and twice as much off the first fixed pulley. In the same way, if there are

FIG. 38.

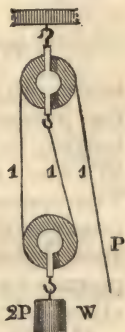
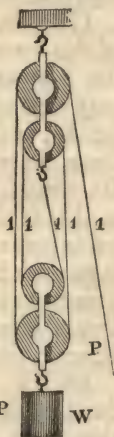


FIG. 39.



several pairs, since all the movable pulleys are supposed to be raised to the same height, half the semi-circumference of a sheaf will roll off from each movable, and twice that quantity from each fixed pulley—the individual action of each pair, consisting of a fixed and a movable pulley, being alone considered. But, when there is more than one pair, each, besides its own portion, must carry away also all the cord, given off by the pulleys, the actions of which have preceded its own.

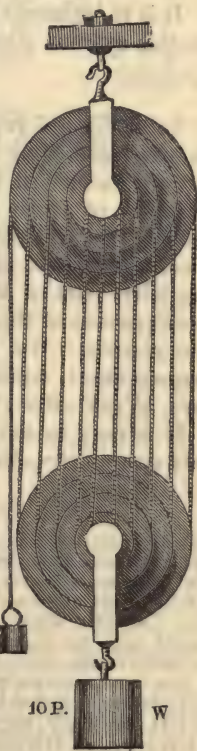
184. Hence, it is evident, that, when the diameters of the movable pulleys are as 1, 3, 5, &c., they will all revolve in the same time; and may therefore be formed of but one piece. Also, when the diameters of the fixed pulleys are as 2, 4, 6, &c., they will revolve in the same time with each other, and with the movable pulleys: or, if they are as 1, 2, 3, &c., they will revolve in the same time with each other:—and, in either case, they may be made of the same piece.

FIG. 40.

185. *White's Pulley*, fig. 40, intended to diminish the friction, wear, and tear, &c., is founded on these considerations. It consists of two blocks—a fixed, and movable; the former contains a compound sheaf, the pulleys of which are as 2, 4, 6, &c., or 1, 2, 3, &c., and the latter a compound sheaf, whose pulleys are as 1, 3, 5, &c. This pulley is an example of excellence in theory, being, by no means, necessarily accompanied by excellence in practice: its construction, and use, involve difficulties which allow it rarely, if ever, to be, actually, applied:—it is scarcely possible to prevent the cord from slipping in the grooves, and other inconveniences, almost invariably, attend its use.

186. In calculating the effect to be derived from pulleys, we must take into account the relative directions of the power, and resistance. And the weight will always be found equal to “the power, multiplied by twice the cosine of the angle, formed by either cord with the direction in which the resistance acts, and divided by the radius.”*

187. When each movable pulley hangs, by a separate cord, and the extremities of the cords are attached to a fixed support



* For, let the pulley H, fig. 41, from which the weight W is suspended, be sustained by the cord EHD. The portion of W supported by EH is equal to the portion sustained by HD [181]. And the weight is equal to the sum of their

N, fig. 42, D being a fixed pulley, intended to alter the direction of the power, if n is the number of movable pulleys, $W = P \times 2^n$. To be convinced of this, we have only to examine, what multiple of P is sustained, by each part, of every cord; and what number of cords, actually, support W . In the present example, of the four cords which sustain the weight, the pressure on each of the two, connected with the power $= P$; the pressure on the next $= 2P$; and that, on the last $= 4P$. This is indicated by the numbers, attached to the different cords. Hence the cords, which support the weight, sustain $P + P + 2P + 4P = 1 + 1 + 2 + 4 \times P = 8P$.

And $W = 8P = P \times 2^3 = P \times 2^n$.

It is to be borne in mind, that each cord, added to this system, *doubles* the effect.

FIG. 42.

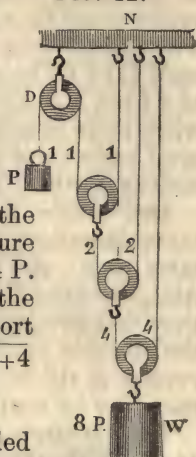


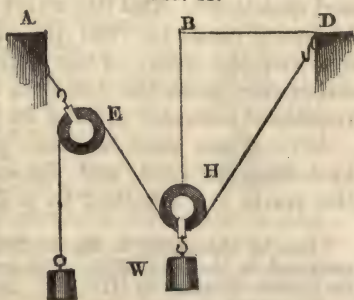
FIG. 43.

188. Fig. 43 represents a similar system, in which the same number of movable pulleys is used:—but, in this case, $W = P \times 3^n$. The number of cords supporting the weight is increased; and we can ascertain the mechanical advantage, in this case, also, by examining what part of the weight, is sustained, by each portion of the rope; and adding together the results. We, thus, find that, with an arrangement, containing three movable pulleys, $W = P \times 3^3 = P \times 3^n$.

It is easy to see, that each cord, added to this system, *triples* the effect.



FIG. 41.



effective parts—or, since the tensions are equal, to twice the effective part of one. Let HD, one of them, be resolved into HB, efficient (because opposed to gravity) and BD, wholly inefficient. The weight may be represented by 2 HB; while the forces, expended in sustaining it, may be represented by 2 HD:—and the part of them, which belong to the power, by HD. Hence $P:W::HD:2HB$. But, if HD is radius, HB will be cosine of the angle DHB, made by one of the cords HD, with BH, the direction in which the resistance acts. Calling this angle a ; $P:W::R:2 \cos. a$. And $W = \frac{P \times 2 \cos. a}{R}$.

189. If the extremities of the cords are fastened to the weight itself—the whole being suspended from a single point of support N, fig. 44, we are to subtract the amount of the power, from that of the weight—as determined, in the former instance [187]. Hence $W = P \times 2^n - 1$. For, estimating, as before, the pressure sustained by each cord; and adding the results; we find that, of the three cords which now sustain the weight, the pressure on the one to which P is attached = P; that the pressure on the next cord = 2 P; and that the pressure, on the last = 4 P. Therefore the cords, which support the weight, sustain $P + 2 P + 4 P = 1 + 2 + 4 P = 7 P$.

And $W = 7 P = 8 P - P = P \times 2^n - 1$.

The mechanical effect is diminished, because the weight is sustained by one cord less than in the former system—the tension of that cord being = P.

In this system, each additional cord more than *doubles* the effect.—It is merely fig. 42, reversed.

190. It may be modified, like what has been already described [188], so as to assume the form, represented, fig. 45; and we are to subtract the amount of the power, from that of the weight—as determined, in the *former* case [188].—For, estimating the pressures sustained by the different cords, and adding the results, we discover that, with three movable pulleys, $W = 26 P = 27 P - P = P \times 3^n - 1$.

The mechanical effect is diminished, in the same way, and for the same reason, as with the system, fig. 44.

In this case, each cord more than triples the effect.

A system of pulleys having but a single cord, although less powerful than a corresponding system having two, three, &c., is much more convenient for ordinary purposes.—When there is more than one cord, the pulleys soon come into contact; and their effect then ceases. Besides, a system with several cords is more difficult to be fixed, applied, and managed.

191. THE WHEEL AND AXLE is a modification of the lever with unequal arms. It consists of two parts:—the wheel—or something tantamount to it—which causes the power to describe a large circle: and the axle—which causes the

FIG. 44.

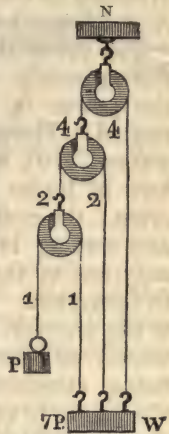
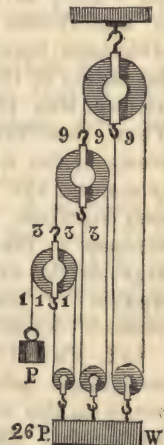


FIG. 45.



power to describe a smaller one. The cord, connected with the power, is applied to the rim of the wheel E, fig. 46; and that which is attached to the weight, to the axle D. A ratchet wheel, which I shall describe presently, prevents the weight from running down—if the action of the power is, from any cause, interrupted. The wheel and axle, like the pulley [179], is resolvable into a system of levers, having a common fulcrum—the centre of the axle, fig. 47—and coming into action successively, only one of them being, at any time, in operation. The radius of the axle is the shorter, and the radius of the wheel, the longer arm; the weight being attached to the former; and the power to the latter.—Hence, from the properties of the lever [158], when there is equilibrium, $P \times \text{the arm to which it is attached} = W \times \text{the arm to which it is attached}$. That is, “the power, multiplied by the radius of the wheel, is equal to the weight, multiplied by the radius of the axle.” The mechanical advantage being due, to the difference between the radius of the wheel, and that of the axle, the greater this difference, the greater the effect. When, therefore, we desire to increase the efficiency of the wheel and axle, we must increase this difference, by making the wheel larger, or the axle smaller; or by doing both together. But there must necessarily be a limit to such increase, or diminution—otherwise the wheel will become too large, or the axle will be made so small as to be, no longer, capable of supporting the weight. This inconvenience is removed, by the following contrivance—

192. THE DIFFERENTIAL AXLE is constructed on the great mechanical principle [152] that the effect of any machine, depends on the excess of the velocity of the power, over that of the weight. It consists of an axle, having its two portions A and B, fig. 48, of different diameters. B, the smaller, lets down the rope, and, consequently, the weight, while A, the larger, coils it up, and, therefore, raises the weight. If the two parts of the axle were of the same diameter, the rope would be coiled up, and let down to an equal extent;—in which case, the weight would move, neither up, nor down. The smaller the difference between the diameters of A and B, the less

FIG. 46.

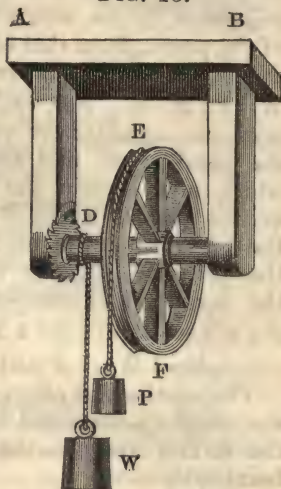
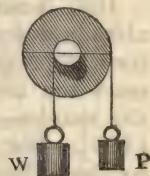


FIG. 47.



the weight will be raised, with a given motion of the power; and the greater, therefore, must be its mass—that its momentum may be equal to that of the power. And, since we can make the two diameters as nearly equal as we please, there is no limit to the effect of such a machine, but the strength of the materials of which it is formed—and the more powerful, the stronger it is.

The differential axle has been long used by the Chinese.

193. We may use a winch, handspikes, &c., in place of the wheel, but the principle is the same: for the power, in all these cases, describes a circle, which occupies the place of the circumference of the wheel.

194. EXAMPLES OF THE WHEEL AND AXLE.—The *capstan*, used in ships, is a species of wheel and axle. It consists of a vertical beam, which, being made to revolve by handspikes, or *capstan bars*, inserted into its upper portion, draws the rope, or chain, with great force.

The *windlass* resembles the capstan, in form, except that the portion, on which the rope, or chain, is coiled, is horizontal; and the handspikes move, in a vertical plane.

The capstan is more convenient than the windlass, since its effect is produced *continuously*: but the force is derived from muscular strength, and not, as with the windlass, from the weight of the body—which is a disadvantage.

The *crane*, also, is a kind of wheel and axle, &c.

195. COMBINATIONS OF WHEELS AND AXLES.—A number of wheels and axles may be made to act together: but, then, they require to be modified:—the axle becomes, what is called, the *pinion*—a small wheel, working into the large one, belonging to the next wheel and axle. Wheels are sometimes made to drive each

other, by teeth, as in fig. 49.—The teeth of the pinions, are called *leaves*. Such a system enables us to increase, either the mass, or the velocity, of the resistance.

FIG. 48.

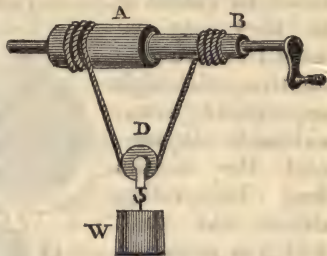
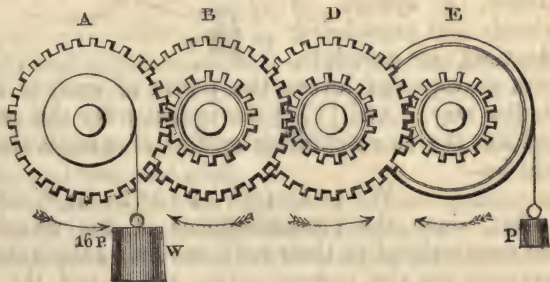
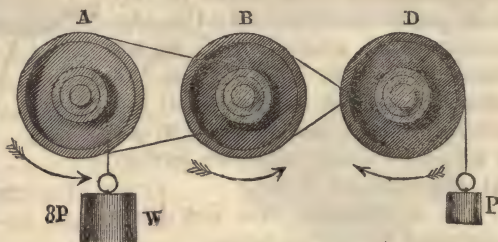


FIG. 49.



196. Sometimes, wheels are made to act together by bands, as in fig. 50. This is a very convenient arrangement; since, by means of it, they may be used to drive one another, although separated by a considerable space; and the motion may be either *direct*—as that, which is imparted by B, to A: or

FIG. 50.



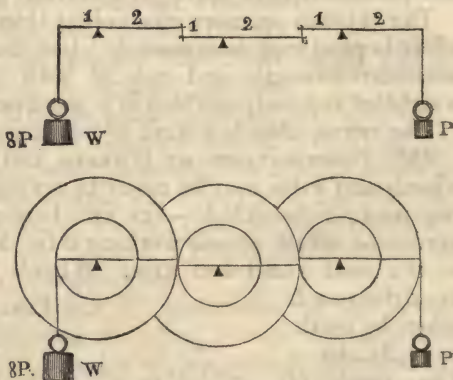
reverse—as that, which is imparted by D, to B.

197. Sometimes, wheels are made to work together, by mere friction; which gives an extremely smooth, and noiseless motion, and is very convenient, where the resistance is not great—as in certain portions of the machinery of cotton mills, &c.

198. With a system of wheels and pinions “the power, multiplied by the product of the numbers of teeth in the wheels, is equal to the weight, multiplied by the product of the numbers of leaves in the pinions.”—The radii of the wheels, are the longer arms, and the radii of the pinions, the shorter arms of such a system of levers

FIG. 51.

as we have already examined [177]. This is evident from fig. 51, which represents a system of wheels and axles along with the *corresponding* system of levers—these levers, only, to which the mutual action of the wheels and axles is referable, being represented. Hence, a system of wheels and axles being identical, in principle,



with a system of levers, the power of each is calculated in a similar way. And [177] the equation for the system of levers, and for the corresponding system of wheels and axles, fig. 51, will be—

$$W \times 1 \times 1 \times 1 = P \times 2 \times 2 \times 2; \text{ or } W = 8P.$$

But, since the circumferences of the wheels and pinions are proportional to their radii, we may substitute these circumferences, for the corresponding radii—and the equation then

becomes “the power, multiplied by the product of the circumferences of the wheels, is equal to the weight, multiplied by the product of the circumferences of the pinions.” This enables us to estimate the effect, when the wheels act on each other, either by bands or friction. And, as the numbers of teeth, or leaves are, respectively, proportional to the circumferences of the wheels, and pinions, when teeth are used, we may substitute, for the circumferences of the wheels and pinions, the numbers of teeth they, respectively, contain.

EXAMPLE 1.—There are three wheels, A, B, and C; and three pinions, D, E, and F. A has 97, B 43, and C 84 teeth; D has 12 leaves, E 15, and F 17. How many pounds, attached to the wheels, will retain, in equilibrio, 432 lbs. attached to the pinions?

$$P \times 97 \times 43 \times 84 = W \times 12 \times 15 \times 17$$

$$\text{That is, } P \times 350364 = W \times 3060$$

$$\text{And } P \times 350364 = 1321920 \text{ lbs.}$$

$$\text{Hence } P = \frac{1321920}{350364} = 3.773 \text{ lbs. nearly.}$$

EXAMPLE 2.—In a system of wheels and pinions, driven by bands, there are four wheels, the circumferences of which are, respectively, 34, 27, 56, and 62; and four pinions, the circumferences of which are, 11, 13, 14, and 17. What is the ratio of the weight to the power?

$$P \times 34 \times 27 \times 56 \times 62 = W \times 11 \times 13 \times 14 \times 17$$

$$\text{That is } P \times 3187296 = W \times 34034.$$

$$\text{Hence } W:P::3187296:34034:93.65:1, \text{ nearly.}$$

EXAMPLE 3.—A system must consist of three large, and three small wheels, acting by bands. The circumferences of the latter are as 8, 10, and 12; and of two of the former as 45, and 55:—what must be the circumference of the third wheel, so that the weight may be 127 times the power? Let x be the circumference of the required wheel. Then

$$P \times 45 \times 55 \times x = P \times 127 \times 8 \times 10 \times 12$$

$$\text{And } 2475x = 121920. \text{ Therefore}$$

$$x = \frac{121920}{2475} = 49.26, \text{ nearly.}$$

In figs. 49, 50, and 51 the diameters of the wheels are supposed to be twice those of the pinions:—therefore, in fig. 49, $W=16P$: and in figs. 50 and 51, $W=8P$.

199. DIFFERENT KINDS OF WHEELS.—Wheels are divided into crown, spur, and bevelled gear.

The *crown wheel* is so called, on account of its resemblance to a crown—having its teeth perpendicular to its plane.

200. The *spur wheel* has its teeth—which are continuations of radii—fixed on its rim. When the wheel is of large size, the

rim is connected with a boss, in the centre, by arms—as in B, fig. 52. When it is smaller, the rim and boss are united, by a thinner portion: and it is, then said to be a *plate wheel*. When still smaller, the entire wheel is of uniform thickness. The axis upon which a wheel revolves, is termed a *shaft*, or *spindle*. If the power, to be transmitted by the wheel, is considerable, the latter is fastened to the shaft, by one or more wedges, called *keys*, which are forced into grooves—cut transversely, in the boss, through which the shaft passes—and which rest upon flat faces, formed on those parts of the shaft, immediately under them.

The *annular wheel* has the pinion B, fig. 53, within it. The friction is less when the pinion is inside, than when it is outside the wheel.

201. When one wheel drives another, the former is called the *driver*, and the latter the *follower*. If a wheel is used merely to transmit motion, between two other wheels, it is called a *carrier*: and alters the direction of motion, but not the velocity.

When a wheel A, fig. 52, drives a pinion B, the latter should have, at least, eight leaves. But when the pinion drives the wheel, the former should have, at least, six leaves.

202. Sometimes a *rack*—which is a straight bar, having teeth on one of its sides—is driven by a pinion: and, sometimes, a pinion, by a rack.

203. *Bevelled wheels*.—The wheels, which work together, are not always in the same plane.

In such a case, those which have oblique teeth, and are termed “bevelled wheels,” are generally employed. They are the frusta of cones, channelled from their apices to their bases.—The mode in which they are constructed, and the kind of action they exert upon each other, may be understood from A and B, fig. 54.—The axles E and D, may form any angle which the circumstances require.

FIG. 52.



FIG. 53.

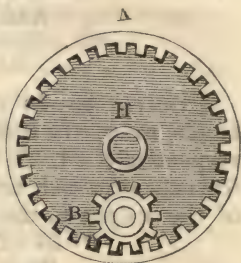
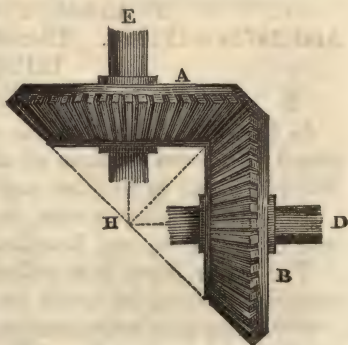


FIG. 54.



204. When bevelled wheels, having different diameters, are to work together, the sections of those cones, of which they may be considered portions, are found as follows.—Let AB, fig. 55, be the greatest diameter of the large wheel: and BD that of the smaller. Bisect AB, in X: and BD, in Z. At X and Z erect perpendiculars intersecting each other, at E. Join E with A, B, and D:—the resulting triangles will, if they revolve, respectively, on XE and ZE, form cones: and ASPB, BPHD may be supposed to generate the required bevelled wheels.—The sum of the angles made by EB will be 90° : all corresponding points of the two cones will have the same relative velocity, and they will roll on each other.

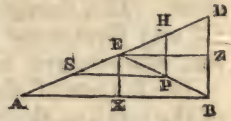


FIG. 55.

205. Sometimes, in the rude machinery of country mills, &c., the *trundle* or lantern, supplies the place of a pinion. It consists of an axis, DE, fig. 56, and two circular discs, A and B—connected by rods, or spindles, which are placed near the circumferences of the discs.



FIG. 56.

206. The *ratchet wheel*, fig. 57, to which I have already alluded [191], is used to prevent the rope, or chain, from being uncoiled, by the action of the weight or resistance, should any cause relax, or destroy the power.—It can turn in only one direction—that, which allows the power to act: motion in the opposite being prevented, by the ratchet A dropping into the notches, in succession, as B revolves.



FIG. 57.

207. When the ratchet is attached to a capstan, the notches are inclined equally, at each side; and the ratchet may be made to act both ways—by causing it to abut against the notches, as represented, by BE, or B'D, fig. 58:—we may thus prevent, or allow motion, in either direction at pleasure. The ratchet is attached to the capstan, and travels round along with it; the notches, into which it drops, are fixed to the deck, in a circle round its base.



FIG. 58.

208.—TEETH OF WHEELS.—It is very important that teeth and leaves, working together, should roll, and not drop, nor slide on each other—either of which latter would cause wear, and loss of power.

When teeth *fall* on each other—being unconnected with the resistance, during the drop—they acquire an increased velocity,

and, therefore, a momentum, which is injurious to the machinery, and is productive of no useful effect, since the motion is too sudden, and of too short duration [6], to be communicated to the rest of the train :—consequently it cannot increase the work done. This dropping of the teeth, always causes noise :—hence we may form some idea of the goodness of mill-work, &c., by the, comparative, silence with which it acts.

The defects of wheels are, generally, due to the incorrect form of the teeth :—their accurate construction, therefore, becomes a matter of great importance.

209. The *pitch* of the wheel, is the width of a tooth and a space, measured on the *pitch circles*, which are the working circumferences of the two wheels, acting together—or those circles of each, which may be considered to come into contact, during their revolution.

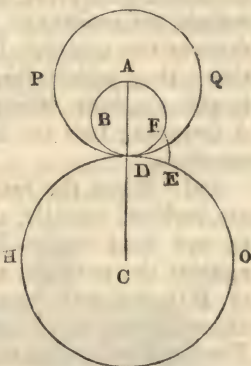
The *line of centres*, is a line passing through the centres of the pitch circles, and the point of contact. The part of the tooth outside the pitch circle, is called the *face*, and that which is inside of it the *flank* of the tooth.

The face of the tooth is an epicycloid, &c. : its flank is a radial line.

The curves, which answer best for teeth, are the epicycloid* and involute.†

210. To describe *epicycloidal teeth*. The diameter of the *generating circle*, of one wheel, should be equal to half the diameter of the pitch circle of the other.—Let HO, fig. 59, be the pitch circle belonging to one of the wheels which are to work together—and the teeth of which are to be described; let EQ, be the pitch circle of the other : and let AC, be the line of centres. If the generating circle BF is made to roll on the pitch circle HO, F, some point of it, will describe the epicycloidal curve FE.—This will be the face of the required tooth. The flank may be described with a radius.

FIG. 59.



Epicycloidal teeth act perpendicularly to the line of centres, at the instant of crossing it.

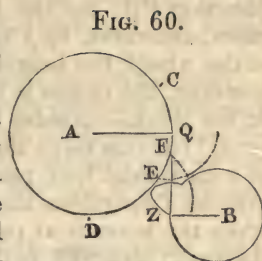
Two wheels with epicycloidal teeth will not work well together, unless they are equal.—To obviate this inconvenience, the same generating circle is, sometimes used for both wheels.

211. To describe teeth, which are the *involute of a circle*. Let A and B, fig. 60, be the centres of the pitch circles, belonging to the wheel and pinion, on which the teeth and leaves, are to be

* *Epi*, upon : and *kuklos*, a circle. *Gr.*

† *Involvo*, I roll upon. *Lat.*

formed. Take EF equal to the base of the intended tooth, and fix, at any point, C—to be determined by the height of the tooth—one end of a cord, or thread. Let this cord lie along the circumference, and reach to E. Its extremity E, will, if rolled off, describe a curve:—this will be the face of the tooth. Take $FD = EC$; fix one end of the same cord at D, and let its other extremity F describe a curve, intersecting the former.—The space between the circle, and the intersection of the curves will be the tooth. The flank may be described by a radius. This tooth, marked on the other pitch circle, will be the leaf of the pinion.



212. Involute teeth do not slide, nor drop, but roll on each other; and since a line QZ, passing through the point of contact, will always be tangential to the circumferences of the wheel and pinion, their mutual action will [111] be most favorable to the communication of motion, from one to the other. A difference between the lengths of their radii does not injure the mutual action of wheels having involute teeth:—so that any two wheels of the same pitch will work well together.

Involute teeth have an oblique action, and throw a greater divergent strain on the axis of wheels than other teeth.

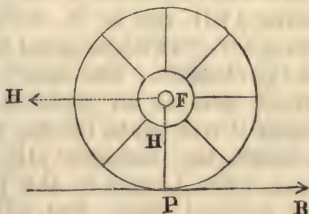
213. A pinion with involute teeth will work a rack, having teeth that are straight sided, and inclined to their pitch line.—Involute teeth, strain a rack very little by lateral pressure.

214. If the number of teeth, in a wheel, is an exact multiple of the number of leaves, in the corresponding pinion, the same leaf will always come into contact with the same teeth: and the injurious effect, of any inaccuracy of workmanship, will be greatly increased.—To prevent this inconvenience, a tooth called the “hunting cog” is added to the wheel.

Wooden and metallic teeth work together, with little, or no noise.

215. *Wheels of Carriages.*—The difficulty of drawing a load, arises from the friction between the axle and the box of the wheel. PF fig. 61, may be considered as the lever in action: F being the fulcrum; H the resistance—at the point where the axle and box are forcibly rubbed together: and PB the direction of the power.—As far as momentum is concerned, it is evidently the same, whether the axle is drawn along FH, or the point P is moved in the

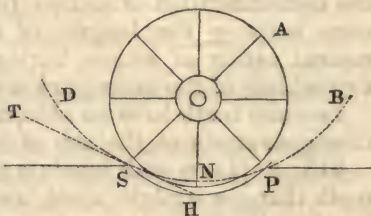
FIG. 61.



direction PB; for the friction of the axle and box is in both cases, overcome, by a force, acting at P. The longer the radius of the wheel, the longer the arm at which the power acts. If, however, the radius is too great, the spoke will be too heavy, or too weak.—Besides the horse will draw at a disadvantage, since [137] his force should be applied nearly, in the direction of a horizontal line, passing through the axle. The trace, however, as Deparcieux has shown, must not be exactly horizontal, when the horse is at rest: but should slightly descend towards the road: since he pulls by his weight, and by lowering his chest—his hind feet being used as a fulcrum. We shall find, also, that a portion of the power is usefully employed, to diminish the effect of gravity, in producing friction. It is evident, that the smaller the radius of the axle, the better—provided it is sufficiently strong.

216. High wheels are drawn over obstacles, more easily, than those which are low:—whether these obstacles arise from hollows or prominences. For, a large wheel will sink either but little, or scarcely at all, into a rut, SHP, fig. 62—which is equivalent to an inclined plane HT. For, the larger wheel—a portion of which is represented by the dotted line DNB—will, evidently, be less affected by the rut, than the smaller one A.

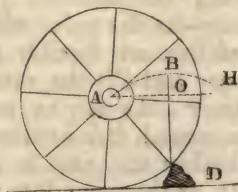
FIG. 62.



217. The sinking of an inelastic road—one of sand, for example, or of clay—produces an uncounteracted pressure, in front of the wheel. Any road, that yields under the weight of the carriage, gives rise to an effect which is equivalent to a continued ascent. Roads over bogs, however good in appearance, will, if carefully watched be perceived to sink beneath the wheel; and to rise again when the pressure is removed.

218. If an obstacle, such as a stone, D, fig. 63, is to be overcome, a large wheel is better, for the purpose, than a small one.—The centre of gravity of that part of the load, the weight of which is borne by the wheel, may be supposed to be at the axle, and it must, while describing a curve ABH, rise to B, through the distance OB—which is equal to the height of the obstacle. The larger the curve—which acts as an inclined plane—the easier it will be, to lift the weight, at A, through the distance OB—as will be seen, when I come to the properties of the inclined plane. But, as the length of

FIG. 63.



the curve, is proportional to the radius which describes it, the longer, the radius, the better:—that is, the larger the wheel, the more easily it passes over stones, &c.

219. The fall of the wheel off an obstacle, injures the road:—hence, wherever the latter is crossed, by an elevated pavement, a row of stones, or any substance higher, or harder, than the general surface, a hollow is soon formed, at each side of the pavement, &c. The same cause makes the ruts of a neglected road to deepen rapidly.

220. Low fore wheels cause a carriage to be more easily turned; but, ordinarily speaking, they have no other advantage. They increase the friction; since, to pass over a given space, they require to revolve more frequently than those which are larger.

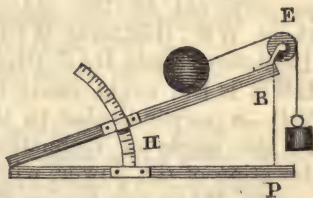
221. When *dished* wheels descend into a rut, the spokes assume the position, best adapted, for supporting the strain, which is thrown upon them—since they are then perpendicular, or nearly so; but their advantages seem, on the whole, to be, at least, counterbalanced, by their disadvantages.

222. A carriage with springs is more easily drawn, than one which has none; because—on account of its inertia [6]—it has not time to sink, or rise, at every trifling inequality that presents itself to the wheels. This is particularly true, if the motion is rapid.

223. When springs connect the axles and wheels, with the rest of the vehicle, not only the carriage itself, but the horses, also, are saved from the shocks, produced by the ruggedness of the road.

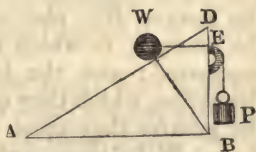
FIG. 64.

224. THE INCLINED PLANE—is a smooth plane AB, fig. 64, making with the horizon, some angle BAP, called “the angle of inclination.” BP, the sine of this angle, is the *height* of the plane; AP its cosine, is the *base*; and AB, the radius, A is the *length* of the plane.



225. If a body is kept in equilibrium, on an inclined plane, the power may act in a direction parallel to the length; or to the base; or—in general terms—it may make any angle, with a perpendicular to the length. Calling the length L; the height H; and the base B; if the power acts in a direction parallel to the length, $P : W :: H : L$.—For, a body W, fig. 65, is kept at rest, on the inclined plane, by three forces [108]—the power, represented by WD; gravity,

FIG. 65.



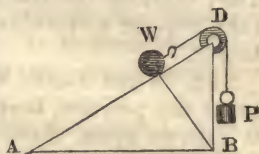
by DB : and the reaction of the plane, by BW . Therefore $P : W :: WD : DB$. But, since the triangles BDW , and ADB are similar, $WD : DB :: DB : AD$ —that is, $:: H : L$.

226. When a horse draws a load, upon an inclined plane, to a certain extent he lifts the load.—Thus, if the rise is one in thirty, he lifts the thirtieth part of it. For gravity is to its effective part $:: DB : WD :: AD : DB :: L : H$.—Therefore, the effective part of gravity is equal to $\frac{H}{L} \times$ the force of gravity.

227. If the power acts parallel to the base, $P : W :: H : B$. For the body W , fig. 66, is kept at rest

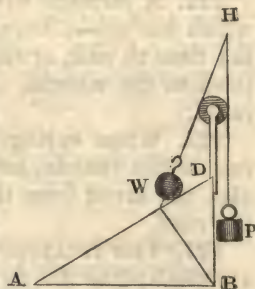
FIG. 66.

by three forces—the power, represented by WE ; gravity, by EB ; and the reaction of the plane, by BW . Hence $P : W :: WE : EB$. But, since the triangles BWE , and ADB , are similar, $WE : EB :: DB : AB$ —that is, $:: H : B$.



228. Whatever may be the direction of the power, $P : W :: \text{sine of the angle of the plane's inclination} : \text{sine of the angle, made by the direction of the power, with a perpendicular to the plane}$.—For, the body W , fig. 67, is kept at rest by three forces—the power, represented by WH ; gravity, by HB ; and the reaction of the plane, by BW . Therefore, $P : W :: WH : HB$. But, the sines of angles being proportional to the sides opposite to them, $WH : HB :: \text{sine } WBH : \text{sine } HWB$. Therefore, since DAB (the angle of inclination) $= WBH$, and HWB is the angle, made by the direction of the power with WB —a perpendicular to the length of the plane, $P : W :: \text{sine of the angle of inclination} : \text{sine of the angle, made by the direction of the power, with a perpendicular to the plane}$.

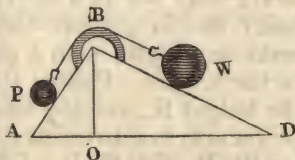
FIG. 67.



229. When two bodies P and W , fig. 68, support each other, on inclined planes, which have a common height, BO , “one of them, is to the other, as the lengths of the planes, on which they rest:”—because

FIG. 68.

the longer the planes, the greater the amount, to which the bodies are supported; and the less, therefore, the action, which they exert:—hence, the greater they must be, to produce a given effect. Also, as P and W balance each other, the efficient part of the force, derived from each, must be the same.—Let us call this f ; and



in the first instance, let us suppose W to be the weight. Since the direction of the power, is parallel to the length of the plane [225], $f:W::BO:BD$. Next, let P , be the weight:—for the same reasons, $f:P::BO:BA$. Alternating these two proportions we have—

$$f:BO::W:BD, \text{ and}$$

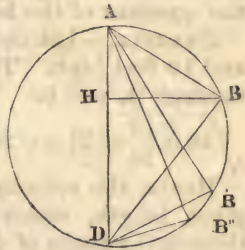
$$f:BO::P:BA.$$

Hence $W:BD::P:BA$: and alternating,

$$W:P::BD:BA.$$

230. DESCENT OF BODIES, DOWN PLANES, AND CURVES.—“A body, will, under the influence of gravity, fall through a vertical diameter, AD , fig. 69, and any chord AB , or BD , joining either of its extremities, in the same time.” If the body is kept on the chord, by means of an inclined plane

FIG. 69.



the reaction of the plane, represented by DB ; and gravity, by AD ; and it will describe the resultant AB , in the same time [106] as any side of the rectilineal figure, representing the forces which produce it, would be described, by the force corresponding to that side.—Hence AD and AB would be described in the same time. In the same way $B'D$, the resultant of $B'A$ and AD would be described in the same time as AD . Also $B''D$, the resultant of $B'A$ and AD , in the same time as AD .

If the chords DB , DB' , &c., are inclined planes; when AD represents the whole effect of gravity, acting on a body, descending along them, each of them will represent its efficient part, or the accelerating force—which, therefore, will vary, as their lengths, respectively:—that is, as the space to be described, under its influence.

231. This enables us to find, in what time, a body would descend, through any inclined plane:—since, if the given plane is AB , fig. 69, we have only to produce the line AH , representing its height; and, from B , to draw a line, perpendicular to AB , and intersecting AH produced, at any point D . The body will descend, along the plane, in the same time as [230] it would, under the influence of gravity, have fallen from A to the point of intersection D .—For, if we draw a circle through the three points A , B , and D , AD will be a diameter; and AB , a chord joining one of its extremities.

232. If the arcs DB' , and DB'' are very small, they may be considered as coincident with their cords; and a body may be supposed to descend, through them, also, in equal times.

The same thing is true, if the body is retained in these arcs, by a string, &c.

233. The time, during which a body would fall down an inclined plane, is equal to “the square root of the quantity obtained, by dividing twice the length by $32\frac{1}{6}$, and then multiplying the result by the quotient of the length divided by the height.”*

EXAMPLE.—In what time will a body fall down an inclined plane, the length of which is 20, and its height 10 feet?

$$\sqrt{\frac{40}{32\frac{1}{6}} \times \frac{20}{10}} = \sqrt{\frac{40}{32\frac{1}{6}} \times 2} = \sqrt{\frac{80}{32\frac{1}{6}}} = \sqrt{2.4870} = 1.577''.$$

234. The velocity, acquired by a body, in falling down an inclined plane, is equal to what is acquired, by falling through its height.—That is, “it is equal to the square root of the product, obtained by multiplying together twice the length, the quotient of the height divided by the length, and $32\frac{1}{6}$.”†

EXAMPLE.—Let the plane, as in the last case, be 20 feet long, and 10 feet high. The velocity of the body, after falling down through it, will be

$$\sqrt{40 \times \frac{10}{20} \times 32\frac{1}{6}} = \sqrt{20 \times 32\frac{1}{6}} = 25.364 \text{ feet, per second, nearly.}$$

Hence, the velocity, acquired by falling down a plane of a given length, varies as the square root of its height. And, though the times of descent through different chords are equal, the velocities, acquired in falling, are not so.

235. If the arcs are not *very* small, the times of descent through them will not be equal.‡

* For, the time of descent is the same as that, during which the body would fall through the diameter AD, fig. 69. That is [60], T being the time,

$$T = \sqrt{\frac{2AD}{32\frac{1}{6}}}. \text{ But since } AD:AB::AB:AH, AD=AB \times \frac{AB}{AH}.$$

$$\text{Or, calling } AB, L; \text{ and } AH, H; AD=L \times \frac{L}{H}.$$

And, substituting this value of AD, in the equation $T = \sqrt{\frac{2AD}{32\frac{1}{6}}}$, we get $T =$

$$\sqrt{\frac{2L}{32\frac{1}{6}} \times \frac{L}{H}}.$$

Since $T = \sqrt{\frac{2AD}{32\frac{1}{6}}} = \sqrt{\frac{4 \text{ radius}}{\text{force of gravity}}} = 2 \times \sqrt{\frac{\text{rad.}}{\text{f. of grav.}}}$, when the force of gravity is constant, T varies as the square root of the radius.

† For, V being the velocity, $V =$ the square root of the product obtained by multiplying together the force of gravity, and twice the space [58]. But [226] the effective part of gravity is, in this case, represented by $\frac{H}{L} \times 32\frac{1}{6}$:

and the space = L.—Therefore $V = \sqrt{2 \times L \times \frac{H}{L} \times 32\frac{1}{6}}$.

‡ For the descent through the different chords DB, DB', &c., fig. 69—which are also the sines of the angles DAB, DAB', &c., belonging to the respective right-angled triangles—are made in equal times, because [230] these chords indicate that part of gravity, which produces motion, in the directions which they represent;—and, in proportion as they are increased—that is, in proportion as the body has to traverse a longer space—the efficiency of gravity, the moving

236. But, if the body traverses, a *Cycloid*—the curve described by every point of a carriage wheel, as it rolls along a plane—it will descend through both large, and small arcs, in equal times.*

237. THE WEDGE, is used for splitting wood, &c. A very common form of this mechanical power, is represented, fig. 72. It consists of one or more *movable* inclined planes, which follow the same laws, as those which are fixed.—If, instead of drawing the body up an inclined plane, the inclined plane

force, is also increased. When a body moves in the arc of a circle, the effective part does not vary as the arc to be described; but as the sine of the angle, measured by that arc.—For the body B, fig. 70, if it describes the arc BO, must move in the tangent BP. But, BH, representing gravity; and PH being parallel to CB, BP will represent the effective part of gravity. Therefore gravity:its effective part::BH:BP. And, since the triangle BHP and BCD are similar, BH:BP::BC:BD. Hence, gravity:its effective part::BC:BD. And the effective part of gravity = $\frac{\text{gravity} \times \text{BD}}{\text{BC}}$.

Consequently, it varies as $\frac{\text{gravity} \times \text{BD}}{\text{BC}}$, or—since

gravity and BC (the radius) are constant—as BD.

That is, as the sine of the arcs BO, B'O, &c.; but not, as the arcs themselves—which are the spaces to be traversed.

* For, the efficient part of gravity will then be proportional to the amount of the curve traversed.—Let AB, fig. 71, be parallel to XZ. Let DN, EM, OI, and SR, be perpendicular to AB. If the circle T is rolled along AB, any point of it, P, will describe the cycloid BPA. DE, and EH are tangents to the curve, at the points D, and E; and, from the nature of the curve, are parallel to OP and SP—chords of the circle OTP; and the cycloidal arc DEP is double the chord OP; EP is double the chord SP, &c. Since DF is a tangent to the curve, at D, when the body is at that point, it may be considered as moving along an inclined plane DF—or, as DEN and OPI are similar, along OP; and, for like reasons, when at E, along an inclined plane SP. But [230] the effective part of gravity is, in such a case, proportional to these planes:—that is, it varies as DF:—consequently, as 2 DF (=2OP); and, as the curve DEP (=DE), That is, the accelerating force, varies as the space to be described—which, therefore, must always be described, in the same time.

It is curious that a body will descend, by a cycloid, more quickly than by any other line, whether straight or curved; a fact which has been applied to practical purposes.

A body at P, suspended by a cord CP, will be made by means of cycloids CA, and CB—arranged so as to bend the chord—to describe the cycloid APB similar and equal to them. A body will vibrate in nearly equal times in very small arcs of a circle [232], also, because the curve at P, the vertex of the cycloid, is nearly coincident with a circle described with a radius CP—the latter being a common radius of curvature at P.

FIG. 70.

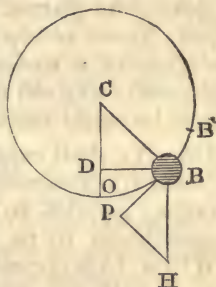
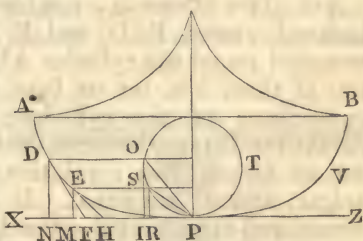
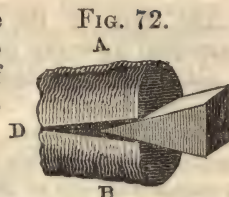


FIG. 71.



is drawn under the body—so as to raise it, the inclined plane, will be changed into one species of wedge, the properties of which, may be easily inferred, from what I have already said [227].

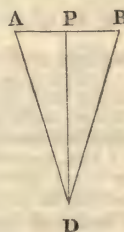


238. When there are two inclined planes, having a common base, the back of the wedge is the sum of their heights; the action of the power is perpendicular to the back; and the effect of the wedge is [76] in directions perpendicular to the lengths of its planes.

239. There are two great sources of difficulty in calculating the effect of a wedge.—First, the momentum, imparted to it, is generally derived from a hammer, &c., the velocity of which cannot be easily estimated; secondly, its friction is enormous.

240. We shall consider only, the isosceles wedge, ADB, fig. 73—which is generated by the motion of an isosceles triangle, parallel to itself, along a right line perpendicular to its plane. With such a wedge, $P:W::$ its back:twice its height; or::twice the sine of half the angle at the vertex:twice the cosine of the same angle.—For, since the planes AD, and DB, are equal, the effect of both is double the effect of one. But, with AD alone, $\frac{P}{2}:\frac{W}{2}::$

FIG. 73.



AP:PD::sine ADP:cos. ADP. And (multiplying all the terms by 2) $P:W::2 \times \text{sine ADP}:2 \times \text{cos. ADP}.$

FIG. 74.

241. THE SCREW is a combination of inclined planes, P, D, and E, fig. 74, wrapped round the cylinder AB. Any one of them has, for its *base*, the circumference of the cylinder; for its *height*, the distance between the threads; for its *length*, one revolution of the spiral: and all are equal. It may be considered as generated, either by wrapping one inclined plane PEH, several times, round the cylinder AB:—in which case, there will be, practically, as many inclined planes, as distinct spirals. Or wrapping the inclined plane BDEP, fig. 75, once round the cylinder HO:—so as to form but a single spiral.

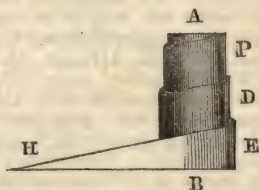
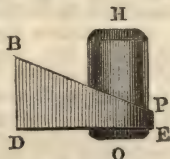


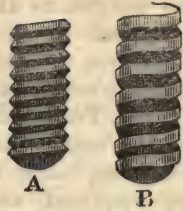
FIG. 75.



242. The threads of a screw are sometimes angular, as in A,

fig. 76 ; and sometimes square as in B :—each kind has its advantages, and disadvantages. When the threads are square, the *height* is a thread and space. The manner, in which the threads are formed, is a matter of considerable importance : since in many instances much depends on their accuracy. The distance between two threads, when they are angular, or a thread with a space, when the threads are square, are called the *pitch*. A screw is *right*, or *left handed*, according to the direction of the spirals. The *solid* screw A or B, fig. 76, works in what is called the *nut*—or *hollow* screw.

FIG. 76.



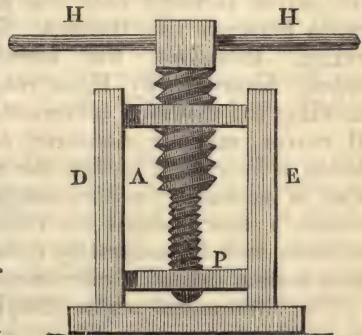
243. Since the power describes a circle, the plane of which is perpendicular to the axis of the cylinder, it acts in a direction parallel to the bases of the inclined planes, of which the screw consists.—Hence [227] B, being the circumference of the cylinder, and H the *pitch*, $P:W::H:B$.

244. There are, therefore, two methods of increasing the power of the screw : the pitch may be diminished, or the diameter of the cylinder may be increased :—but the former, if carried beyond certain limits, will weaken the screw too much ; and the latter may render it too gross for the object in view.

245. APPLICATION OF THE SCREW TO VARIOUS PURPOSES.—The *differential* screw, like the differential axle [192], acts by diminishing the distance, through which the weight is moved—compared with that, which is traversed by the power. The upper bar of a frame, DE, fig. 77, carries a hollow screw, which corresponds with the larger part of the solid screw A. P is a bar, movable only in a vertical direction, and carrying a hollow screw, corresponding with the smaller part of A. When the handle HH is moved round, P is raised, or depressed ; and with a force depending, on the difference between the pitch of the larger and smaller parts of A.

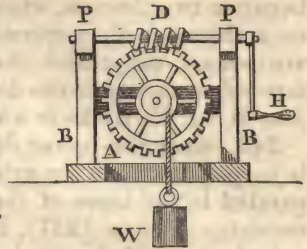
FIG. 77.

If these pitches were equal, P would, in reality, be moved neither up nor down :—for it would be raised, or depressed, by the one part of the screw, just as much as it would be depressed, or raised, by the other ; and the two effects would then counteract each other. But, if the pitch of the lower screw, is less than that of the upper, every revolution of HH will raise, or depress P, a distance, equal to



that difference: and the power will [152] be as much less than the weight, as this difference is less than the circular space, described by the power.—And, since we may diminish this difference, as much as we please, without lessening the strength of the machine, we may increase its effect, to any desired extent.

246. *The endless screw.*—When a screw D, fig. 78, is used to turn a spur wheel, A, it is termed “endless.”—So many threads, only, are required, as will act upon the wheel—the teeth of which are set obliquely, that their surfaces may be, as much as possible, in contact with the screw. Such a machine has great power; since one revolution of the handle H—fixed on the axis of the screw—moves the circumference of the wheel through a distance equal, only, to a tooth and a space; and, when the power is relaxed a ratchet wheel [206] is not required to prevent the descent of the weight.



247. A wheel is never employed to turn a screw, except when waste of power is not material:—as, for instance, when the screw is applied, in the musical box, to uniformly retard the motion of the works, by making air-vanes revolve, with great rapidity. If the screw is used in this way, the threads are made to approach more nearly to parallelism with its axis, that the power may be more effective in the direction of rotation.

248. *The micrometer screw,* is an instrument, used for measuring extremely small spaces. Its principle may be understood from fig. 79.—While the handle H

FIG. 79.



makes an entire revolution, the point P—or an index attached to it—moves through only the distance between two threads. Dividing, therefore, the circular space, described by H, is really dividing the distance, traversed by P. The arc, through which H moves, may be measured on a graduated circle:—as the circle is increased in size, the number of perceptible divisions, also, is increased: and, consequently, the number of parts, into which a space, equal to the distance between two of the threads, may be accurately divided. Every adjusting screw is, to a certain extent, a micrometer.

The differential screw [245] has been applied to the construction of a micrometer, of sufficient delicacy to measure the millionth part of an inch.

CHAPTER III.

Regulation of Machinery—Modification of Power, 249.—The Fly Wheel, &c., 251.—The Fuzee of a Watch, 256.—The Pendulum, 257.—The Balance, 278.—The Governor, 284.—Contrivances for changing the Direction, &c., of Motion, 287.—The Parallel Motion, 295.—The Crank, 297.—The Sun and Planet Wheel, &c., 302.—The Eccentric, &c., 311.—Velocity Combinations, 316.—Gearing, 322.—Reversion of Motion, 325.—Disadvantages incident to Machinery—Friction, 329.—Pressure of Bodies in Motion, 338.—Friction-rollers, 351.—Rigidity of Cordage, 353.

249. REGULATION OF MACHINERY—MODIFICATION OF POWER.

I am now to speak of the various modifications of momentum, which do not, like those we have, up to this time, examined, necessarily suppose [74] such a change of its elements as—friction, &c., not being taken into account—will leave their product unaltered. What I am about to describe, are intended to suit the force, rather to the nature, than the quantity of the work to be done; and they have not, like the mechanical powers, for their primary object, the increase, or diminution of either the mass or the velocity, belonging to a given momentum.

250. *The working point* of a machine is that at which the power is changed, from what it is, to what the nature of the work requires it to be.

251. THE FLY WHEEL, &c.—Many means are used, to accumulate a force, which is insufficient for the purpose intended; if applied as fast as it is generated.—Thus, a hammer would produce but little effect, were it allowed merely to fall by its own weight: but, being urged *continually*, during its descent, it is capable of causing very considerable results, by giving out, instantaneously, the force which it has been, for some time, accumulating. The bullet, which is fired from a gun, accumulates force, during the entire time the powder is exploding. Flails, whips, hatchets, &c., owe their efficiency to a similar principle.

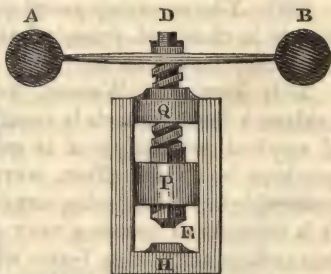
252. But, in the arts and manufactures, the *fly wheel* is the great magazine of motion. In many cases, the power, without being accumulated, is quite insufficient for the work to be done:—as in certain mills, for rolling metal, &c.—In such circumstances, it is allowed to act on the fly wheel, for some time; and, when force enough is obtained, the metal, &c., is introduced. Sometimes, without a fly wheel, the machinery would be injured, by sudden and great changes in the resistance.—Thus, while a ponderous hammer is being raised, the motion is

slow, on account of the great weight to be lifted; but when the hammer is allowed to fall, the machinery being freed from the resistance which retarded it, would, without a fly wheel, revolve with inconvenient, and often dangerous, velocity. Sometimes, it is necessary to obtain a uniform power, from a very variable prime mover—as when steam is applied to communicate motion, through the medium of the crank.—The fly wheel, changes this variable, into what may be considered as a nearly uniform force.

253. The fly wheel is a heavy rim of metal, connected by light spokes, with the centre, on which it revolves. Its effect depends on inertia [5].—The mass is so large, that it may gain or lose a considerable quantity of motion, without its velocity being sensibly affected: the number of particles being, comparatively, so great, that when the gain, or loss, is divided between them, each has an exceedingly minute quantity.

254. For the sake of convenience, and to diminish the resistance of the air, &c., the fly is generally, though not necessarily, in the form of a wheel:—but any mass of matter would answer the purpose; and, the farther it is from the centre of motion, the greater its efficiency, in regulating the velocity. Sometimes—as in machinery for punching the patterns in brass fenders, &c.—the *fly* consists of two balls, A and B, fig. 80, placed at the extremities of a strong rod; and the effect is transmitted to the working point, by the screw D. A fly, with arms four feet long, and balls weighing one hundred cwt. each, will, if it makes 60 revolutions per minute, urge the die against the metal to be punched, with about the same force as 7,500 lbs., falling from a height of 16 feet.

FIG. 80.



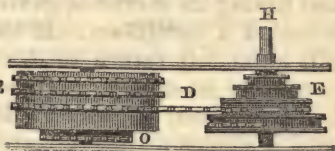
255. When a fly wheel is intended to accumulate force, it should be placed near the power. When it is used to prevent inconvenience from sudden alterations in the resistance, it should be placed near where these alterations occur. When it is applied for the purpose of changing a varying into a uniform force, it should be as close to the working point as possible:—hence, in the steam engine, it is near the crank.

256. THE FUZEE OF A WATCH.—When a watch is first wound up, the spring exerts too much, and when it is nearly down, too little power.—In a watch, or clock, the power employed should be only sufficient to supply what is consumed by friction, &c. If it exceeds that amount, it will cause unnecessary wear and

tear, by making the different parts of the works act on each other with unnecessary violence:—and it may even produce irregularity, in the rate of going. The smaller the force required by a clock, or watch, to keep it in motion, the better.

If the spring were to act directly on the works, the power would sometimes be far too great:—the fuzee E, fig. 81, is intended to prevent this. It is, simply, an axle of varying diameter:

FIG. 81.



which increases the leverage of the power, when it is small; but diminishes it, when the power is great:—and, thus, renders the motion equable. In winding a watch, the fuzee—which somewhat resembles the frustum of a cone, and has a spiral groove on its surface—is turned round, and the chain is coiled upon it, but is uncoiled from the cylinder B, which contains the spring. One extremity of the latter being attached to the inner surface of B, and the other to the fixed axis, on which B revolves, it is coiled up, when B is turned round. A ratchet-wheel [206] allows the fuzee to move in one way, but not in the other, without driving the machinery—since it is connected in that direction, by the ratchet, with a toothed wheel, which communicates motion to the entire train of works. When, therefore, the spring uncoils itself, by its elastic force, it coils the chain again on the cylinder, and uncoils it from the fuzee—which it causes to revolve. In reality, the curve of the fuzee is an hyperbola, its axis H being the asymptote—a line constantly approaching to, but never coming in contact with it.

257. THE PENDULUM is used to regulate the motion of clocks, &c. Its properties were discovered, accidentally, at Pisa, by Galileo; who remarked that a chandelier, set in motion by those who lighted it, vibrated in equal times. The Arabs are known to have used the pendulum, as a measure of time, for astronomical observations, so early as the year 1000 of the Christian era; although it was not applied, to the same purpose, in Europe, until so long afterwards.

258. The accurate and uniform measurement of time is one of those things, which are not sufficiently appreciated, because the want of them has not been felt, for a long period. To mark the progress of time, recourse was had, formerly to expedients, the best of which, were but rude and imperfect,—compared with the methods we employ.—Such were the various kinds of *clepsydra*.* Also, the candles, anciently used by the Anglo-Saxons:—these contained within them, at certain distances, balls of

* *Kleptō*, I steal; and *hudōr*, water; *Gr.*: as they generally marked the progress of time, by the stealthy descent of water.

metal, which, by successively falling into a metallic basin, gave notice that certain portions of time had elapsed.

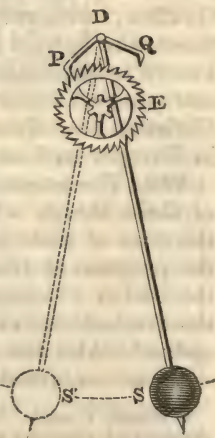
259. Were the weight to act freely, on the works of a clock, it could not be made to measure time, correctly; since it would be impossible so to adjust the power to the resistance, that the motion would be perfectly uniform. This difficulty is, however, removed, by the application of the “pendulum.”

260. Any body, capable of turning round on a horizontal axis, and having its centre of gravity beneath the line of suspension, is called a pendulum. If thrown out of equilibrium [96], it will ultimately return to it, of its own accord:—but in tending to recover its original position, it will move from side to side, for some time, the arcs it describes becoming gradually less, until it attains a state of rest. This motion is termed *oscillation*.

261. The pendulum, as applied to a clock, is shown, FIG. 82. fig. 82, in a position, perpendicular to the plane of vibration. It consists of a compact mass of matter P, connected with the centre of motion, by a light and slender rod DF, HT—supposed to be broken at F and H, that it may occupy less space in the figure. This rod is terminated, at its upper extremity, by a thin spring, ED, which rests, in the slit, made in a piece of brass D, called the *cock*.—It is evident, that the pendulum does not exactly turn on D, as a centre; but that the thin spring bends freely, so as to accommodate itself to the different positions, which the pendulum assumes, during vibration. If it can be avoided, the cock should be attached, not to the works of the clock, but to a wall, or a strong shelf—that “the rate of going” may not be affected by a vibratory motion being communicated to the point of suspension. The pendulum is connected with the works, by the *crutch* VRA, which oscillates on a horizontal axis AB; and it passes through a fork V, with sufficient freedom, to allow the sliding motion, consequent on its vibration.

262. Fig. 83 represents a pendulum, in the direction of the plane in which it moves. Pallets P, and Q, are fixed on the axis D—which corresponds with AB, fig. 82—and act, alternately, on the *escapement wheel* E.—The latter is called, also, the *swing wheel*, and, along with the pallets, is termed the *escapement* or *'scapement*. When the pendulum reaches either extremity of its arc of vibration, it checks, by its inertia, through the medium of one of its pallets, the motion

FIG. 83.



of the swing wheel; and, consequently, arrests the action of the moving power—causing the whole train to stop for a very short period. The tendency of the pendulum to vibrate in the opposite direction, disengages the pallet, and allows the wheel to move, until it is again stopped by the other pallet. At the moment each pallet is being disengaged, it receives a slight impulse from the swing wheel, which replaces the motion lost by friction, &c.

263. Two vibrations of the pendulum cause the swing wheel to move through the space of one tooth. If, therefore, it has 30 teeth, with a pendulum vibrating seconds, it will make one revolution in a minute.

264. The “centre of suspension” of a pendulum, is that point, around which, as a centre, it moves. The “centre of gyration” is that point at which the sum of the forces, which tend to turn the pendulum round, in opposition to gravity, may be considered as concentrated. The “centre of oscillation” is that point at which gravity—acting on all the particles, in lines perpendicular to the horizon, and tending to restore the mass to its original position, when moved round on its centre of suspension—is concentrated. It is this action of gravity which makes the pendulum continue to oscillate, for some time after the force of gyration has ceased to operate. The “length” of the pendulum is the distance between the centres of oscillation and suspension.

265. The properties of the pendulum depend on the principles which relate to bodies falling down an inclined plane, and which I have already explained [230, &c.] But for the resistance of the air, and friction, a pendulum having fallen down the curve—in which it is kept by a string, rod, &c.—would rise to the same height, on the opposite side; and, once put in motion, would continue to oscillate for ever.

266. Since, as I have already shown [236], bodies descend in equal times through unequal arcs of the cycloid, many contrivances have been devised, to make the pendulum move in that curve; but they have not been found convenient in practice. The pendulum, therefore, generally, vibrates in *small* circular, [232] or nearly circular [261], arcs.—It is suspended, in various ways, but is, most ordinarily [261], attached, by a thin spring.

267. If the force of gravity is supposed to be constant, “the time of oscillation varies as the square root of the length of the pendulum.”*—Hence, one that is four times as long as another will vibrate twice as slowly.

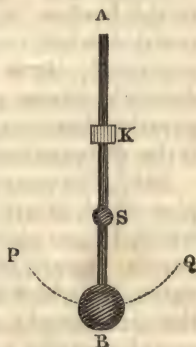
268. The *length* of the pendulum—that is, the distance between the centres of suspension and oscillation, is obtained, “by dividing the square of the distance of the centre of gyra-

* For [233 note] T varies as the square root of the radius, which, in this case, is the length of the pendulum.

tion from the centre of suspension, by the distance of the centre of gravity from the centre of suspension."—But we may obtain it practically—as suggested by Captain Kater—if we find some other point, which being made a new centre of suspension, will leave the rate of vibration unchanged.—This will be the centre of oscillation; since the centres of oscillation and suspension are commutable. And the distance between the two points of suspension, will be the *length* of the given pendulum. If a right angled cone—that is, one the diameter of whose base is equal to its altitude—is suspended by its vertex, its centre of oscillation is in the centre of its base: but, if it is suspended by its base, its centre of oscillation coincides with its vertex.

269. It is evident that we increase the *length* of the pendulum, by diminishing the distance between the centres of gravity and suspension:—since decreasing the divisor, increases the quotient. We may, therefore, increase its length, without altering the mass of matter which it contains. The construction of the *metronome* is founded on this principle.—It is an instrument used for measuring *musical* time, &c.; and consists of a pendulum, AB, fig. 84, having a heavy knob of brass, B, attached to a slender rod, and a movable knob, K, which is capable of a sliding motion, between A and the point of suspension, S. When K is raised, or depressed, the centre of gravity of the whole is raised up towards S, or is moved down from it; which causes the pendulum to oscillate with less, or greater rapidity. When the centre of gravity is brought nearer to S, its leverage, and, by consequence, its efficiency in overcoming the inertia of the pendulum, is diminished. A pendulum vibrating

FIG. 84.



Seconds.		Inches
$\frac{1}{4}$	must be	2.44616 long.
$\frac{1}{2}$	"	9.78465 "
1	"	39.13860 "
2	"	156.65544 "

270. It is very important that the arcs of vibration should be small [235]. A seconds' pendulum would require 1.0736", to describe an arc of 120°; and 1.18", to describe a semicircle.

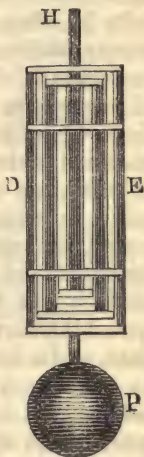
271. The pendulum cannot be an accurate regulator of time, unless it is always of exactly the length which is suited to the place.—If a seconds' pendulum is made the tenth of an inch shorter, it will gain 114" in 24 hours. If one that vibrates seconds, at London, is carried down into the mine at Dolcoath,

in Cornwall—which is 1,050 feet under the level of the sea—it will require only $0.99997''$, to make one vibration: but, if it is carried to the summit of Mont Blanc—which is 15,780 feet above the level of the sea—it will require $1.000753''$.

272. The pendulum is very much altered in length, by changes of temperature.—For it is found that one made of iron, which, on a cold day, would regulate a clock with perfect accuracy, on a hot day, will make it lose several seconds.

273. Many contrivances have been devised, for counteracting the changes, due to temperature.—Among others, the *Gridiron Pendulum*, HP, fig. 85. It consists of a combination of rods, of different metals; which are so arranged, that, when some of them, by expanding in one direction, raise the bob, P, the others, by expanding in the opposite, depress it. The rods which require to be longest, are made of the less expandible metal: that the two opposite expansions may be equal.

FIG. 85.



274. The *Mercurial Pendulum*, RE, fig. 86, is another of these contrivances: it has been long in use; and is, at present, very commonly adopted.—Mercury, contained in the glass cylinder D, expands with the increase of temperature, and raises the centre of gravity of the pendulum—which, on the other hand, is depressed by the expansion of the rod RR. There is an adjusting screw P; and an index H, to mark, upon a graduated arc, the extent of vibration.

FIG. 86.



275. A piece of straight grained deal, boiled in a chandler's vat, and gilt, is found to make a pendulum rod, but little affected by atmospheric changes.

276. Since the pendulum acts by the force of gravity, which varies, at different distances from the earth's centre [70], it enables us to measure the height of mountains, by ascertaining how its rate of vibration is changed, when it is brought to their summits.

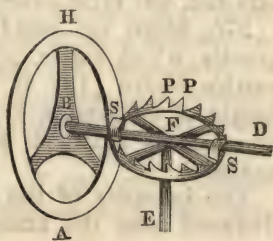
The intensity of the force of gravity, at a given place, is deduced from the number of oscillations, made there by the

pendulum, before it returns to a state of rest, after being set in vibration.

277. The oscillation of the pendulum is employed very beautifully, to exhibit the rotation of the earth on its axis, in a manner obvious to the senses.—A heavy metallic ball, carefully turned—that its shape being symmetrical, and its centre of gravity in the centre of its mass, it may have no tendency, in passing through the air, to move round a vertical line, or otherwise interfere with oscillation—is suspended by a long and slender wire or cord, from a dome, steeple, or some other lofty building, an index being attached to it, so as to point downwards: and concentric circles are drawn on the floor or a table underneath, their common centre being directly under the point of suspension:—when this pendulum is put in motion, it will continue to oscillate for many hours; and its index will cut different portions of the horizontal circles successively—that is, the plane of vibration will seem to rotate. It is, however, the floor or table, on which the concentric circles are described, that moves round, on account of the diurnal motion of the earth. This revolution is not indeed performed round the centre of the circles; but the floor or table revolves, along with the earth, round the earth's axis. A little consideration, however, will show that, as far as the senses are concerned, the effect is the same; and is due, not to the plane of vibration remaining altogether unchanged, but to its continuing parallel with itself, while the point, from which it is suspended, is carried round. The motion of the plane of vibration, in azimuth, will, it is clear, not be uniform, unless with a pendulum suspended actually at a pole of the earth; at the equator it will not have any motion. The revolution of the plane of vibration, takes place in a period exceeding 24 hours—being retarded to a greater or less extent, according to circumstances.

278. THE BALANCE.—It would be impossible to apply the pendulum to a watch, chronometer, &c. Yet these, also, as well as clocks, require some mode of uniformly checking their prime movers. This is effected by the *balance*, which was employed as a kind of fly-wheel, even before the pendulum, to regulate instruments for measuring time. The balance of a watch, &c., consists of a nicely poised wheel A, fig. 87, that plays on pivots turning in holes, which, to prevent the wear arising from the rapid motion, are drilled in steel, the diamond, or some other very hard substance; and it is connected with a fine spring, called the *hair*, or *pendulum spring*. When the balance is turned round, in one direction, the hair spring

FIG. 87.



is coiled up ; but being immediately uncoiled, by its elasticity, it moves the balance, to an equal extent, in the opposite direction. Pallets, fixed on the axis of the balance—termed the *verge*—act on the *crown-wheel* of the watch, just as the pallets of the pendulum act on the *swing-wheel* of the clock [262] :—and also receive impulses from it, while being disengaged, which replace the motion, lost by the balance, on account of friction, &c. :—and thus the vibrations are continued.

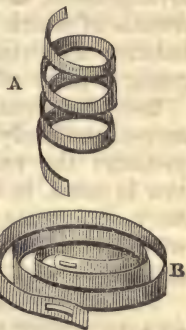
279. The “hair spring” may be either a flat helix,* the coils of which diminish as they approach the centre ; or one, the coils of which are all equal in size.—The former, occupying less space, is used in watches ; the latter, being more regular in its action, is applied to chronometers. A flat helix may be understood from B, fig. 88, which represents the mainspring of a watch : and the other species from A.

280. With a hair spring, of a given thickness, the rate of vibration depends on its length :—that is, on the distance between the point, at which it is attached to the axis of the balance, and the place, where it passes through a notch, cut in a stud—connected with what is called the *regulator* :—the *absolute* length of the spring being of no consequence. When the regulator is moved in one direction, so as to increase the vibrating length of the hair spring, the watch goes more slowly ; and when, in another, so as to shorten it, the watch goes faster.

281. Since the balance of a watch acts as a fly-wheel [253], its effect depends on the quantity of matter contained in its rim, and on the distance of that rim from the centre of motion :—altering either, or both these, would alter the rate of going, since it would give the hair-spring more, or less work to do, in moving the balance ; and would, therefore, cause the oscillation to be more, or less rapid. This affords another method of regulation : which is, however, chiefly confined to chronometers.—Screws, with comparatively large heads, are fixed in the rim of the balance ; and according as these are moved in, or out, the mass of the rim is brought nearer to, or farther from, the centre of motion.

282. It is necessary that the hair-spring once regulated, should continue to be of exactly the same length ; and that the mass of the balance, should remain at the same distance from the centre of motion. But since the fulfilment of these conditions, however desirable, is prevented, by changes of temperature, many methods of constructing “compensation balances”

FIG. 88.



* *Helix*, a spiral. *Gr.*

have been devised.—They are similar, in principle, to the gridiron pendulum [273]: but none of them is so important, as to render a description requisite. A well-constructed ordinary watch is a sufficiently good regulator of time, for most purposes.

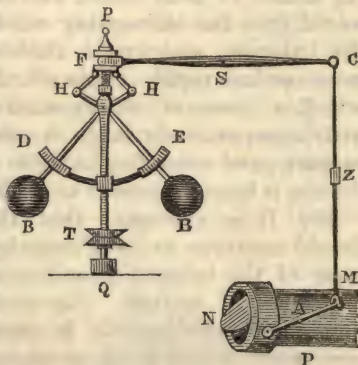
Sometimes the plane of the *balance-wheel*—or that, upon which the pallets act—is perpendicular to the plane of the dial; the movement is then said to be *vertical*. Sometimes it is parallel with the dial; and it is then *horizontal*.—The latter arrangement, in conjunction with certain contrivances, into the details of which it is not necessary for us to enter, allows the balance to swing through a larger arc; and thus the rate of going is more effectually regulated.

283. Sometimes it is necessary to check the action of a prime mover uniformly, and without stopping its effect, even for short periods: the pendulum is then inapplicable. Hence a *fly* or *fan* is used, in musical boxes, in the striking part of clocks, &c.:—being made to revolve with very great rapidity, it meets with such resistance from the air, as retards the motion of the machinery with which it is connected.

Sometimes the fan is so arranged, as that, by turning it on an axis, it may be made to displace a larger, or smaller quantity of air, during its revolution—and thus to exert a greater, or less retarding power.

284. THE GOVERNOR.—When the resistance to be overcome is variable, to an extent which would seriously affect the rate of the fly-wheel, water-wheel, &c., the power itself, also, must be varied.—The “governor” or conical pendulum [126] is used for this purpose, when the prime mover is steam; and, sometimes, also, when it is water. It consists of two rods, carrying heavy balls B, B, fig. 89, and attached to a rod PQ, which is made to revolve, by means of the pulley T, driven by the power. The pendulums are carried round by PQ: and, when the velocity of rotation exceeds a certain amount, they are thrown out by centrifugal force:—their increased divergence depresses the fork F, lying in a grooved ring, which is movable up and down, on PQ, and is so attached, by joints, to the pendulums, that it is lowered, when they rise: and elevated, when they fall. The fork F is at the extremity of a lever, FC turning on some point S. When

FIG. 89.



F is depressed, the rod CM is raised: and, by means of the arm A, the throttle valve N is closed—to an extent, which depends on the velocity with which the governor revolves. The length of CM is adjusted by a simple contrivance at Z.—The details of the governor are variously modified, according to circumstances; but its mode of action will, in all cases, be easily understood, from what I have said.

When the velocity of rotation becomes less than it should be the pendulums fall; and the throttle valve is opened.

285. The farther the balls recede from the axis of rotation, the greater the centrifugal force, with a given number of revolutions per minute, and the greater the tendency to fly out.—But this is nearly counteracted by the increased effect of gravitation: so that, after a temporary derangement of speed, the governor will return very nearly to its original velocity. A sudden and undue change of speed, in the engine, causes the balls to fly out too much; this checks the motion of the engine, and they collapse beyond the proper amount. They will next diverge too much, and afterwards collapse—these alterations continuing, but gradually decreasing, until the engine acquires its proper rate of going.

286. If the governor is attached to a water-wheel, the rod FC, fig. 86, throws into action machinery which, by means of power derived from the wheel itself, lifts or depresses the sluice-gate—so as to increase or diminish the supply of water; and therefore, to increase the power, or lessen it, to the required extent.

When the supply of water is precisely what it should be, to overcome the resistance, the rod FC holds such an intermediate position, as leaves it unconnected with the machinery intended either to raise or depress the sluice. FIG. 90.

287. CONTRIVANCES FOR CHANGING THE DIRECTION, &c., OF MOTION.—*Change from one direction to another. Two wedges,* fig. 90, may be used for this purpose. When the lower one is driven in the direction AL, the upper one raises any thing, placed upon it, in the direction FD.

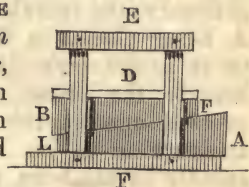
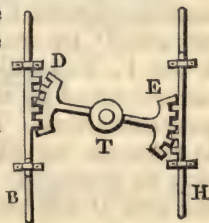


FIG. 91.

288. *Two racks and segments.* When the rack H, fig. 91 is raised, or depressed, the rack B, will be depressed, or raised, by the segment D.



Altering the radii of the segments, will modify the relative velocities of the power, and resistance.

289. If there are only one rack, and one segment, reciprocating rectilinear motion, in one direction, will produce reciprocating circular in another; and *vice versa*.

290. *The Bell-crank*, or angular lever, exemplified, fig. 26, will alter the direction of motion, and modify the relative velocities. The arms may be of any lengths, and form any required angle.

291. The pulley [179], and wheel and axle [191], will change the direction of motion. Also several of the contrivances to be described immediately:—indeed many of them may be applied to more purposes than one; as a little consideration will show, —for instance, they may, sometimes, be made to produce two changes of motion, exactly the reverse of each other. This must be kept in mind.

292. *Reciprocating rectilinear changed into reciprocating circular motion*. Besides the racks and segments [288], we may use the *drill and bow*, fig. 92.—When by means of the handle H, the bow is moved from

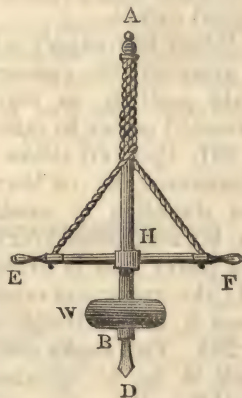
A to B, or from B to A, the pulley P is carried round; and, pressure being applied above the drill, D, it enters the substance to be pierced.



FIG. 92.

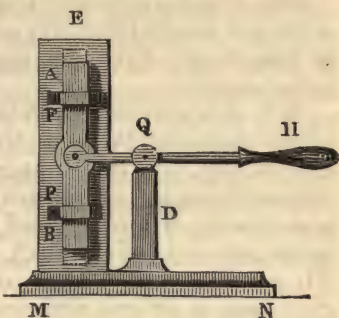
293. Another contrivance, represented, fig. 93, is often employed for the same purpose. It consists of a circular weight W, fixed on a spindle AB; a cord, attached to the inner extremities of the handles E and F, passes through the upper part of the spindle—which turns freely, in H, an aperture of the bar EF: the drill D is fitted to the spindle at B. The point, A, being placed in the hollow, made for it, at the centre of a plate, which is held to the breast, &c., the drill is pressed against the spot where the aperture is to be made: and—the spindle having been turned round, so as to coil the cord upon it as represented—the bar EF is pushed strongly towards D, by means of the handles E and F. This will first uncoil the cord, which, the spindle being carried round by the weight W, will then be coiled in the opposite direction. And, thus, by continuing at the proper times, to force the bar EF, along AB, a reciprocating circular motion may be produced: and, the pressure being maintained at A, the drill D will bore with great facility.

FIG. 93.



294. If the handle H, fig. 94, is moved up, and down, the bar AB, will be depressed and raised, in the guides P, and F by means of a pin, fixed in the rod to which the handle H is attached, and working freely in a slot—or opening, formed transversely, in the middle of AB.

FIG. 94.



295. THE PARALLEL MOTION was invented by Watt, for the purpose of keeping the piston perfectly parallel with the axis of the steam cylinder, while communicating a reciprocating rotary motion to the extremity of the beam. It is founded on a geometrical principle, which may be understood from fig. 95.—Let CE

FIG. 95.

be a rod, turning on C—as a centre; and DF, another rod, turning on D. Let EF, be a rod, attached to CE—by a joint E, and to DF—by a joint F. If the points E and F are made to describe arcs, not exceeding a certain length, P, a point in the connecting rod, exactly between them, while moving up and down, will always be found in the right line NH.—Anything, therefore, attached to P—for example, a pump-rod—will be moved exactly in the direction NH. This principle is applied to the steam engine, in various ways—which may be understood by a single example, fig. 96.—DF, a portion of the beam, occupies the place of the rod, indicated by the same letters, in fig. 95: the rods CE and EF, also correspond, in both figures. Hence, anything attached to P, will be found, continually, in the same right line. And, since the triangles DFE and DQB are similar, the point A will move parallel to the point P:—and, consequently, will always be found, as well as anything attached to it—for instance, the piston rod—also, in the same right line. The dotted lines are

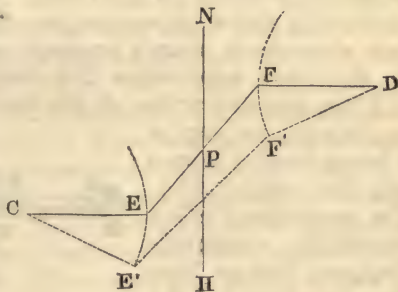


FIG. 96.

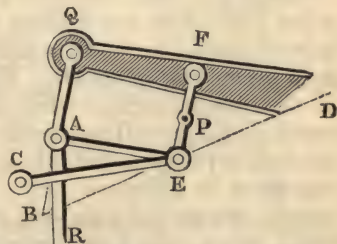


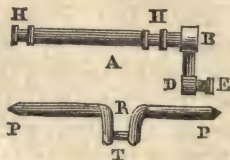
FIG. 96. The dotted lines are

introduced, merely for the purpose of explanation; but they form no part of the parallel motion.

296. Strictly speaking, the point P, figs. 95 and 96, does not move in a straight line, but in a curve—which, however, deviates so little from a right line, as, in practice, to cause scarcely any inconvenience.

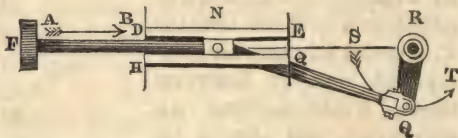
297. *Reciprocating Rectilinear, changed into continued Circular Motion.*—THE CRANK, fig. 97, the contrivance, most commonly employed, for this purpose, is a short arm, or lever, placed, sometimes, at the extremity of the shaft, or axle—as BD, used in certain kinds of steam engine; and, at others, between the extremities—as RT, seen in the turning lathe, &c.

FIG. 97.



298. The crank is often said to destroy power. But it is evident, from the very nature of the lever [175] that, although, when it is employed, the mass of the resistance continually varies, its momentum—friction, &c., not being taken into account—is always precisely equal to that of the power. As the crank approaches the *dead points*—one of which is at S, fig. 98—the action of the power becomes merely a strain on the axle, no part of it being exerted in moving the crank round. The mechanical effect therefore, constantly changes: but so also does the velocity of the point N:—and the consumption of power is altered in exactly the same way. Hence, when the crank is applied to the steam engine, as it approaches the dead points, the motion of the piston P, and, consequently, the expenditure of steam, continually decreases.

FIG. 98.



299. Although the crank does not destroy power *directly*, it destroys it *indirectly*. This arises from what is called the “obliquity of the connecting rod.”—Power is invariably lost, when [132] it is not applied *exactly* in the direction in which it is intended to produce motion:—which occurs, when the crank is to be moved by steam. The piston rod, fig. 98, exerts a force in the direction AB: while the motion, required to turn the crank, is tangential to the curve, at Q. If, therefore, the hypotenuse represents the whole power, a small side will [132] represent its effective part. And that amount of it, which merely strains the axle, &c., will be to the whole :: one of the small sides : the hypotenuse. Thus, it is evident that the power is not entirely effective in turning the crank round, at

any part of its revolution : and that the relative amount of the ineffective part constantly varies.

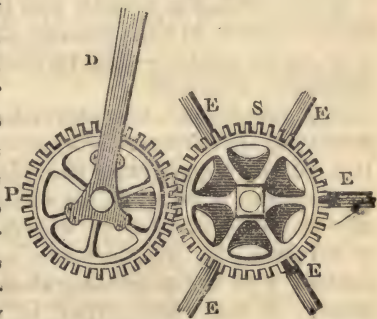
300. A fly-wheel is required, to carry the crank over the dead points; and, also, to render the velocity, with which it revolves, uniform.—But the mechanical effect of the crank is thus made constantly to vary, from 0 to maximum, and from maximum to 0—which, though at first sight, it appears a great inconvenience, is, in reality, the most important advantage, derived from its application to the steam engine: since, by means of it, the motion of the piston, &c., is gradually retarded, as it approaches to, or recedes from, the dead points; and the violent shocks and strains of machinery, which would arise from *suddenly* stopping or bringing into rapid motion, so large a mass of matter as the piston rod, beam, &c., of powerful engines, are completely avoided.

301. When the fly-wheel is inapplicable—as with locomotives, &c., the inconvenience, arising from the dead points, is obviated by the use of two engines—the cranks of which are fixed at right angles, on the same axle; so that, when one is at a dead point, the effect of the other is at a maximum; and their joint action is very uniform.

302. THE SUN AND PLANET WHEEL, &c.—The application of the crank to the steam engine, by Watt, was betrayed through one of his workmen, to a gentleman of Bristol, who took out a patent for it. It was, however, used, long previously, to change reciprocating rectilinear into rotary motion : and its application to the steam engine was patented, several years before Watt's experiments, by Jonathan Hill:—but the patent seems to have been forgotten.

303. Watt, to avoid litigation, adopted, instead of a crank, the “sun and planet” wheel, fig. 99, which is, in reality, a *concealed crank*.—S and P are two equal wheels, connected, by an iron band; the former being, from the nature of its motion, called the *sun*; and the latter the *planet* wheel.—S revolves on its centre; but P is fixed, immovably, to the rod D. P, in going round, moves S; but, when it has made half a revolution, it has driven that tooth of S, with which it was, at first, in contact, one half a revolution—by the action of its teeth, and another half revolution—by its motion round S. The axis, therefore, of S, and the fly-wheel, &c., attached to it, make twice as many revolutions, as if a crank were used.

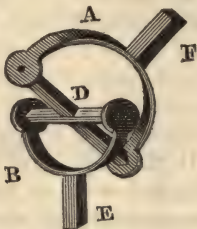
FIG. 99.



The crank is now, almost exclusively, employed.

304. *Circular Motion, in one direction, changed into Circular in another.*—*Hook's universal joint* will change the direction of circular motion. In its simplest form, it consists of two forks, A and B, fig. 100, in which pivots, at the end of the cross D, turn freely. When the shaft E revolves, the shaft F—making some angle with E—is made to revolve, also. This contrivance sometimes assumes a more complicated form. It is used, occasionally, instead of bevelled wheels [203].

FIG. 100.



A spur wheel, working with a crown wheel [199, &c.]: a wheel and endless screw [246], &c., are used, likewise, for effecting a change in the direction of circular motion.

FIG. 101.

305. *Reciprocating Circular, changed into continued Rectilinear Motion.*—*The lever of Lagaroust*, fig. 101, may be employed for this purpose. Hooks A, and B, are moved up and down, by means of the lever EH, turning on a stationary pin, which passes through a slot, cut in DN—to allow it a motion upwards and downwards. While one hook is lifting DN, the other is descending into the next tooth.

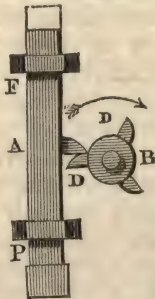


306. *Reciprocating Circular, or Rectilinear, changed into continued Circular in either direction.*—A toothed wheel may be moved through one, or more teeth, at a time, by a ratchet [206], the lower extremity of which is shaped so as to drop between the teeth, and which receives from a lever, &c., a reciprocating motion—in a circle, concentric with the wheel, or in its tangent.

If the ratchet is double, and properly placed, it will communicate motion, in the opposite direction, by merely throwing it over, on its centre.—The ratchet is very often, and conveniently, applied in this way.

FIG. 102.

307. *Continued Circular, changed into Reciprocating Rectilinear Motion.*—A beam, A, fig. 102, having a projecting shoulder, may be lifted by means of a wheel B, on which there are fixed any required number of wipers, D, D, &c. As B revolves, the wipers come, successively, into contact with the projecting shoulder, and lift the beam. When each wiper is disengaged, the beam falls by its own weight. The stampers, of oil mills, are often worked in this way.



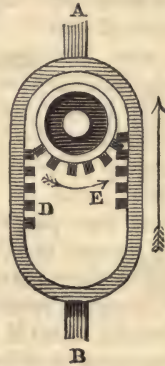
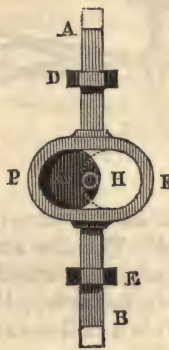
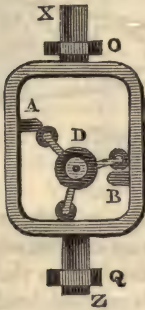
308. If it is necessary to produce rectilinear motion, in the *two* directions, by the apparatus itself, we can use the wheel D, fig. 103, carrying pins—with or without friction rollers—which, acting on a single tooth in each rack, successively raise and depress XZ, in the guides O and Q.

309. The alternate motion may be rendered *continuous*, by means of the contrivance, fig. 104.—The eccentric disc H, as it revolves within PF, raises, and depresses AB, in the guides D and E. The motion of AB is rendered *uniform*, by using a

FIG. 103.

FIG. 104.

FIG. 105.



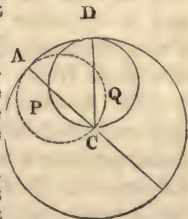
wheel, fig. 105, containing teeth, on only a portion of its circumference:—during revolution, these teeth, acting alternately on the racks D and E, alternately raise, and depress AB.

310. If an annular wheel [200] is rendered immovable; and a spur wheel, of half its diameter, is made to work within it—the centre of the smaller being made to describe a circle round the centre of the larger wheel, any point, in the circumference of the smaller, will be found, continually, in the same diameter of the larger; and anything attached to that point will move backwards, and forwards, in a right line.*

311. THE ECCENTRIC is a very common, and convenient con-

* This may be easily shown geometrically.—Let the larger circle, fig. 106, represent the annular wheel; and the smaller one the spur wheel: and let A be the point of contact of the two. If the smaller have moved from the position indicated by the dotted circle, that point of it which was, at first, in contact with the larger wheel, has moved to P, in the same diameter of the larger.—For, the arcs DP and DA are equal; since the one is the measure of the angle ACD, which is “central” with reference to the larger circle; and the other is double the measure of the same angle, which is “inscribed” with reference to the smaller. Hence DP contains twice as many degrees as DA. But—since circles are proportional to their radii—any number of degrees, in one, will be equal in length, to double that number in another, the radius of which is only half as great

FIG. 106.

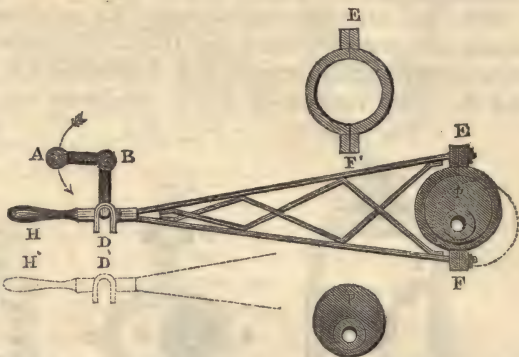


The same reasoning would show that the point of the smaller wheel, originally in contact with the larger, will be found, successively, in every other point of the same diameter of the larger.

trivance, for producing reciprocating rectilinear, from rotary motion. It is a species of crank; but it does not weaken the axle, by causing it to be of an angular form:—and it is, besides, applied more easily than the crank. It consists of a disc P, fig.

FIG. 107.

107, turning along with the axle to which it is attached, but with which it is not concentric. The distance between the centre of the crank, and the axis of the axle, is called the *throw* of the crank. A circular strap EF, works on P; and



is made in two parts that, as it wears, it may be tightened, by means of screws, at E, and F. The disc and strap cannot separate, since one of them plays in a groove which is formed in the other. As the eccentric revolves in its strap, HD is moved backwards and forwards. And if ABD is a bell crank [161], moving round B, a reciprocating motion will be communicated to A. The valves of many steam engines are worked in this way. The different parts of the apparatus are shown separately, also, in fig. 107.

312. *Continued Rectilinear, produced by continued Rotary Motion.*—This may be effected by a wheel, or pinion, working into a single rack [289]. Also, by a solid and hollow screw [242].—If one of these is movable in a direction parallel to its axis, and the other is not so, any thing attached to the former will be carried along with it, when either is turned round.

313. *Continued Circular, changed into Reciprocating Circular Motion.*—We may use, for this purpose, the crown wheel H, fig. 108, having teeth on only a portion of its circumference, and working with the spur wheels A and B.—As H revolves, it acts, alternately, and in opposite directions, on A and B; and a reciprocating circular motion is produced, in the shaft DE.

FIG. 108.

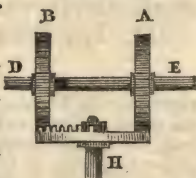
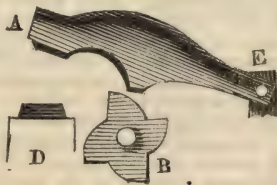


FIG. 109.

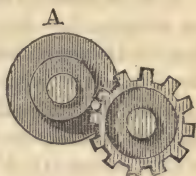
314. A wheel B, fig. 109, carrying any required number of wipers, will communicate a circular motion to the hammer A. As B revolves, the wipers, in succession, raise the hammer which, when the wipers become disengaged, falls by its own weight.



315. *Continued Circular, producing continued Circular Motion, in the same, or in a different direction; and having the same, or a different velocity.*—The wheel and axle [191], drums [196], bevelled wheels [203], &c., may be used to produce this kind of change in circular motion.

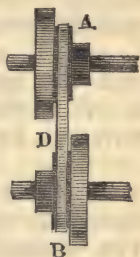
Or let there be a pin, on one of the lateral surfaces, of the wheel A, fig. 110.—When A is made to revolve, the pin, coming successively into contact with the teeth of B, will make it revolve, also. It will revolve but once, however, during as many revolutions of A, as there are teeth.

FIG. 110.



316. **VELOCITY COMBINATIONS.**—It is often of great importance to alter permanently, or temporarily, the velocity with which machinery is driven. Many contrivances are employed, for the purpose:—but I shall describe a few, only, of the most important. We may use drums A, and B, fig. 111, each containing pulleys of different diameters, and of such proportions, as that those which are opposite, may, by the same band, be made to work together—the band being changed, with ease and rapidity, from one pair to another.

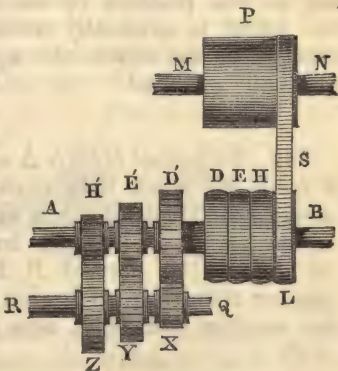
FIG. 111.



317. We may also employ the contrivance represented fig. 112. P is a drum, driven by the prime mover. AB is a shaft,

FIG. 112.

on which four pulleys, and three spur wheels, of different diameters, revolve. The pulley H and the spur wheel H' are fixed, immovably, to the axis AB. The pulley E is immovably attached to the spur wheel E' by a hollow axis turning freely on AB. And the pulley D is immovably attached to the spur wheel D', by a hollow axis, turning freely, on that which connects E and E'. The loose pulley L, turning freely on AB, is used for a purpose to be described presently. X, Y, and Z are keyed on the shaft Q.—If the band, from P, is thrown upon H, H' will move Z:—Y and X will, then, keep E' and E, D' and D, revolving; but, being loose on AB, they will produce no effect. If the band is thrown on E, E' will move the smaller wheel Y:—RQ will, thus, be made to revolve with greater speed. Z and X will, in this case, keep H' and H, D' and D revolving: but, without producing any effect. If the band is, lastly, thrown on D, D' will move the still smaller wheel X:—RQ will, then, revolve



with still greater speed. In this case Z and Y will keep H' and H, E' and E revolving.

318. A similar effect may be produced without the aid of toothed wheels, by the arrangement, fig. 113, D and D' are drums, fixed immovably, on the shaft AB, which is driven by the prime mover; F is a pulley fixed immovably, on the shaft ER, and L a pulley, turning freely, upon it; F' is a small pulley, also fixed immovably on ER, and L' a pulley, turning freely upon it.—If the band T is thrown on F, and T' on L', ER will be made to revolve:—D' will keep L' revolving; but, being loose on the axle, it will produce no effect. If T is thrown on L, and T' on F', ER will revolve, but with less speed:—in this case, T will keep L revolving: but it will produce no effect. The two straps may, by simple contrivances, be shifted together.

FIG. 113.

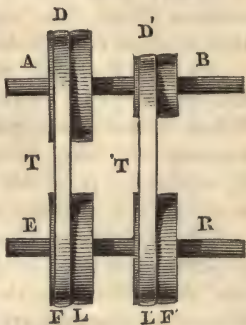


FIG. 114.

319. The velocity may be *gradually* varied, by using two cones A and B, fig. 114, connected by a band D. If A is driven by the prime mover, B will revolve, and with greater or less speed, according to the position of the band. When the latter is gradually moved in one direction, or the other, the speed will be gradually changed.

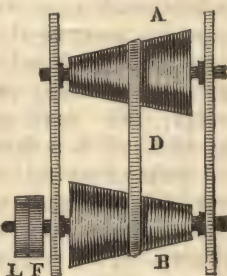


FIG. 115.

320. *Elliptical Wheels* A and B, fig. 115, will, if made to work with each other, produce a *varying* velocity.—Each is supposed to revolve on one of its foci. If the larger part of A acts on the smaller part of B, B's velocity will be greater than that of A; but it will be less, if the smaller part of A acts on the larger part of B.

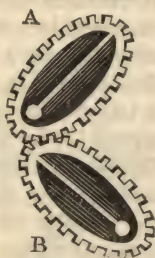
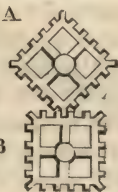


FIG. 116.

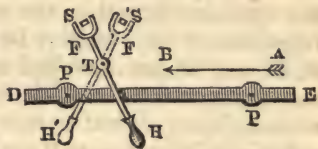
321. *Square Wheels* A and B, fig. 116, will, when working together, produce a velocity which varies, from greatest to least, four times during every revolution of either wheel.



322. **GEARING.**—It would often be attended with the greatest inconvenience, if it were necessary to stop the prime mover, as often as any part of the machinery must be brought to a state of rest.—

Fast and Loose Pulleys.—Machinery may be connected, or disconnected, by what are called “fast and loose pulleys.” They consist of two pulleys, placed together on the same shaft, only one of them—the *fast* pulley—being keyed upon it. When the band is thrown on the loose pulley, the latter will revolve, without the shaft; or the shaft, without the pulley. From the tendency of a band, to get upon the centre of the slightly convex rim of a pulley, it is very easy, by means of a *fork*, worked with a lever, to throw it from one pulley, to the other. This is effected, when the machinery is *self-acting*, by some part of itself. For instance, let S, fig. 117, be a section of the band,

FIG. 117.

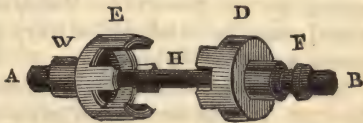


which is to be thrown from a fast to a loose pulley. When DE has—by means of the power—been carried along through a certain space, which is regulated by the position of the pins, P,P; the fork HS, turning on T, as a centre—being acted on, by one of the pins—shifts the band from a fast to a loose, or from a direct to a reversing pulley—or *vice versa*. When it is necessary to move the fork rapidly, a weight is so applied as that, falling suddenly over at the proper times, it accelerates the motion of HS. Fast and loose pulleys are seen in fig. 112—the former being represented by L, and the latter by D, E, and H. Also, in fig. 113, the former being represented by F and F', the latter by L and L'; and in fig. 114, the former being represented by F, and the latter by L.

323. *Clutches*, also, are contrivances intended to throw machinery in, or out of gearing. They are of various kinds; but may be understood from fig.

FIG. 118.

118.—A small disc D contains projections and spaces; which correspond with, and fit into spaces and projections in E—attached, for example, to a wheel, within which the



shaft AB revolves freely. The disc D is capable of being moved along the shaft, by means of a fork, working in the circular groove F; but, since it has a pin, which projects into a longitudinal groove in AB, the latter cannot revolve without making it revolve also. The discs being as represented in the figure, it is evident that AB and D will revolve, without carrying E along with them. But if D is moved on the shaft, until its projections enter the spaces of E, the rotary motion of AB will be immediately communicated to it. If the fork F is brought back again, D and E being no longer connected, the rotary motion of the latter will cease—although AB continues to revolve.

324. When a clutch, fig. 118, is used, the solid parts of the machinery coming *suddenly* into contact, the inertia of the quiescent portion offers a resistance to motion, which, since it is not gradually overcome [6] is the cause of great strain, and wear.—To obviate this inconvenience, clutches have been devised, which—acting by friction—allow the machinery to slip, more or less, until it gradually acquires the proper velocity.

325. REVERSION OF MOTION.—If it is necessary, with a force acting constantly in the same direction, to move machinery, sometimes in one, and sometimes in the opposite direction, the contrivance represented, fig. 119, may be employed.

A, B, and D are bevelled wheels. A and D allow the shaft OR to revolve, without being moved by it. There are portions of clutches at P and Q; and a fork, which works in the circular groove of F—containing the counterparts of P and Q—and which revolves with the axle, but is capable of sliding along it.

When F is in the position represented, it revolves in the fork, without moving any of the bevelled wheels. But if the fork is moved along OR, F locks in the counterpart P, or Q, attached, respectively, to A and D:—this causes A, or D to revolve, along with the shaft, and to move B in one direction, or in the *opposite*. While either A, or D is driven by the shaft, the other revolves freely upon it—producing no effect.

326. If H, the shaft belonging to B, fig. 119, carries a pinion, which works in the rack, attached to a sluice gate; and F is moved by the governor; the quantity of water, supplied to the wheel, may be rendered always proportional to the amount of power required [286].

327. A very convenient reversing apparatus is represented, fig. 120. B, D, and E are pulleys; F, Q, and H, bevelled wheels. D is loose. B, and H are fixed, immovably, on the shaft AP. E and F are attached to a hollow axis, which allows AP to revolve freely within it.—When a band, connected with the prime mover, is thrown on B, the bevelled wheel H, and the shaft AP, re-

volve; and Q, with its shaft N, is moved in one direction, E and F being moved also, but producing no effect. If the band is placed on E, the bevelled wheel F revolves; and Q, with its shaft N, is moved in the opposite direction, B and H being moved also, but producing no effect. The band being thrown

FIG. 119.

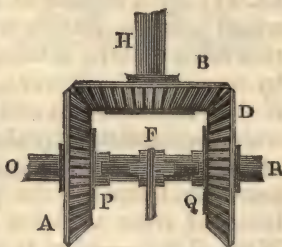
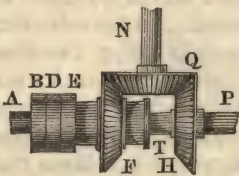


FIG. 120.



upon D, all the bevelled wheels with their corresponding pulleys remain at rest.

328. If the apparatus, fig. 117, is applied to those represented figs. 119 and 120, the pins P.P may be made to disconnect the bevelled wheels from the power; or to cause motion, alternately, in opposite directions.

329. DISADVANTAGES INCIDENT TO MACHINERY—FRICTION.—Hitherto, I have supposed the force to act without any diminution from friction, rigidity of cordage, &c.; in practice, however, these are productive of a great loss of effect. The laws which govern resisting forces are found by experiment.

330. Friction supposes motion and pressure. However smooth any surface may appear, it will, if viewed with the microscope, exhibit a great number of irregularities. When one surface, AB, fig. 121, is placed on CD, another, the inequalities of the one, to a certain extent, sink into those of the other. And, if either surface is moved, these inequalities must be rubbed off—as in the case of two pieces of chalk; or, those of the upper must slide over those of the under surface—the centre of gravity being raised.—Whether the particles are violently abraded, or the centre of gravity is lifted, force is consumed. If the inequalities are to be ground off, the amount of surface must be taken into account; but if they are to be dragged over each other, the amount of surface is of but little consequence—the pressure or weight of the upper body being the chief element to be considered. When, in the latter case, we increase the surface, we diffuse, as it were, the pressure of the upper body over a greater number of particles; but the pressure on each particle will be so much less, as to leave the total amount unchanged.—Hence it is, that a brick may be drawn along a table, as easily, on its broad, as on its narrow side. And a body, *just* sustained on an inclined plane, by friction, will continue to be sustained—however the weight, resting on it, may be increased, or diminished. For, if the tendency to slide is increased, or diminished, friction, the force which counteracts that tendency, is increased, or diminished, and in the same proportion. Hence—

FIG. 121.



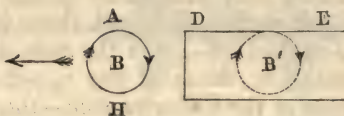
331. Broad-rimmed wheels do not render a carriage more difficult to be drawn, since they do not increase the friction. They diminish the draft, since they do not, so frequently, sink into ruts: and they are not so injurious to the road.—When the surface is very adhesive, they may cause some additional labour to the horse; and they, sometimes, encounter obstacles, which are passed over by narrow ones:—but, on the whole, their advantages are greater than their disadvantages, although unfounded prejudice still prevents their more general adoption.

It must be admitted, however, that certain experiments made by Professor Vince, seem to indicate that friction does not increase quite as rapidly, as the pressure. Whence it would follow, that increasing the surface does, to some extent, increase the friction.

332. Coulomb showed that, when one body rests on another, the friction increases for a certain length of time.—When wood is placed upon metal, it augments for *several days*.

333. *Rifling of guns, &c.*—The effect, arising from the friction of a musket ball, against the side of the barrel, has given rise to what is called “rifling.” Experiments being made with very delicate screens; it was found that, when a ball was fired from an ordinary gun, the apertures made by it, successively, in the screens, showed it to deviate, considerably, from the direction in which it was fired. This is explained by the fact, that the ball B', fig. 122, in passing through the barrel, rubs against one

FIG. 122.



side, DE—and thus acquires a rotary motion, in the direction of the curved arrows. Hence there are unequal frictions, at opposite sides of the ball, since the velocities at these sides are unequal.—The velocity, at H, is equal to the velocity of projection, *plus* that of rotation; and, the velocity at A, to that of projection, *minus* the velocity of rotation. And the divergence of the ball from the direction of projection will be, from A towards H: since it will be more retarded, on the side opposite to that at which it rubs against the barrel—the friction of the air, against it, being greatest, where its velocity is highest. With an ordinary musket, we cannot know what side of the barrel the ball will touch: and therefore, to aim accurately with it, is impossible.—The divergence is sometimes so considerable as to be attended with serious consequences.

334. To prevent these inconveniences, the ball must be made, either not to revolve at all, or to revolve in a known direction.—The former is effected by making the barrel polygonal, instead of circular, the bore being larger at the breech—where it is introduced. In passing through the barrel, the ball is pressed, violently, against every side of the polygon.—This prevents it from having a tendency to rotate, in any direction—and it assumes a polygonal shape.

335. A barrel is rifled, also, by forming a spiral groove round its interior. The ball, in traversing this groove, is made to rotate in a plane, nearly perpendicular to the direction of projection.

Any inconvenience, arising from the centre of gravity not being in the centre of the ball, is obviated by this plan.

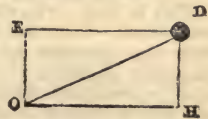
336. *Friction on Planes.*—A body will just *begin* to descend

on an inclined plane, when—friction: pressure::the height of the plane:its base.*

337. It follows that “the line of draft [137] should make an angle with the plane, along which the load is drawn, equal to the angle of inclination of an inclined plane of the same materials, down which a load would just *begin* to descend of its own accord.”† Force will, it is true, be lost, on account of the direction of the power not being that [132], in which the load is to be moved. But some, on the other hand, will be gained, from the friction being lessened, by diminishing the pressure:—and, when the angle does not exceed the proper limit, the gain is greater than the loss.

338. PRESSURE OF BODIES IN MOTION.—The pressure of bodies at rest is termed *statical*; that of bodies in motion, *dynamical*.—Vertical pressure, is diminished by motion parallel to the horizon.—Let a body D, fig. 125, be carried along a horizontal plane, by a force DE: and let gravity be represented by DH: its tendency will be in the direction DO. It is evident that the greater the force DE, the less the relative amount of DH, and the more nearly will DO, concede with DE:—that is, the less will be the action on the plane DE.—Hence, as far as the pressure is concerned, a carriage passing rapidly over a bridge, endangers the latter to a less extent than if the velocity were diminished. It is found in

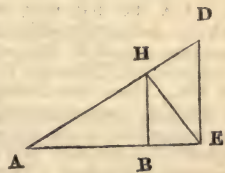
FIG. 125.



* For, let the body be *just* kept at rest, at H, fig. 123. It is acted upon, by three forces; friction, represented by HD; gravity, by DE; and the reaction of the plane, by EH—which is equal and opposite to HE, representing the pressure on the plane.—Hence friction:pressure:: HD:EH. But, since the triangles ADE and EDH, are similar—HD:EH::DE:AE. Therefore friction:pressure::DE:AE. And, calling the height of the plane H, and its base B, friction:pressure::H:B.

FIG. 123.

† For, let AE, fig. 123, on an horizontal plane, represent the entire friction, and EH, any force which would move the body at E. EH is resolvable into EB, opposed to friction: and BH, opposed to pressure.—BH, has diminished friction to the amount of AB. If the power had been in the direction EA, the whole force would not have been expended in overcoming friction. If in the direction ED, no friction would be left—but there would be no motion along the plane.



If, therefore, the friction is represented by AB, HB will represent the corresponding pressure. And friction:pressure:: AB:HB. Hence AHB, will be the angle of inclination [336] of an inclined plane, down which a body would just begin to descend of itself: and, therefore, it is unchangeable. HBA, the angle made by the direction of gravity with the plane is also unchangeable. Consequently HAB (what the sum of AHB, and HBA, wants of 180°), is also, unchangeable. And AE is unchangeable; since it is the total amount of friction.—Hence, EH (not supposed to be in any particular direction) must form one side of the triangle AHE; AE, another side; and (since the angle HAB is unchangeable) some part of AD, the remaining side.

It is evident that the power, required to move the body on the plane, is least when EH, which represents it, is shortest.—But it is shortest, when it is perpendicular to AD.—And then HEA=AHB, because the two triangles HAB

of resistance." Any force, the direction of which makes a greater angle, will cause the body to move along the plane.—The angle of inclination of a plane, down which a body would just begin to move of its own accord [336] is evidently greater, by an exceedingly small quantity, than the limiting angle of resistance.*

340. When the pressure is considered as unity, if the fibres are in the same direction, the friction of

Oak against oak is	0.43
Elm against elm	0.47
Fir against fir	0.56
Oak against fir	0.65

And when the fibres are at right angles, of

Elm against elm	0.100
Oak against fir	0.158
Fir against fir	0.167

The friction of

Brass on soft iron is	0.143
Cast-iron on cast-iron	0.166
Brass on steel	0.166
Brass on cast-iron	0.166
Cast-iron on soft steel	0.166
Cast-iron on wrought-iron	0.166
Cast-iron on hard brass	0.166
Soft steel on soft steel	0.166
Wrought-iron on wrought-iron	0.166
Tin on cast-iron	0.2
Tin on wrought-iron	0.2
Soft steel on wrought-iron	0.2
Brass on brass	0.2
Tin on tin	0.333

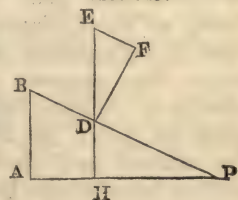
341. When the friction of wood on wood, in repose, is 0.30; in motion it is 0.20. When the friction of metal on metal, in repose, is 0.15; in motion it is 0.15.

342. When the friction of dry wood, on dry wood, is 0.30; the wood being damped with water, it is 0.65; being rubbed with tallow, it is 0.14; and being rubbed with dry soap, 0.22.

343. When the friction of metal on metal is 0.15; the metal

* Let BP, fig. 126, be a plane, down which a body, at D, would just *begin* to descend, by the force of gravity—represented by ED. The part of ED which is represented by EF [132], is just sufficient to overcome friction.—If it were exactly *equal* to friction, EDF would, according to the definition, given above, be the "limiting angle of resistance." But EDF=BPA: since their sides are respectively perpendicular.

Fig. 126.



being rubbed with olive oil, it becomes 0.06; being rubbed with lard, 0.07; with tallow, 0.07; and with lard and black lead, 0.06.

344. The experiments on friction, made as yet, even by men of the greatest eminence, are but approximations to what should be the results: and the most careful experimentalists frequently differ very much in the conclusions to which they come—

The researches of Coulomb on this important subject, give rise to the following principles—

Friction, generally, varies according to the nature of the surface.—In new wood, planed, it will be represented by half the pressure; in metals, by one-fourth; and in wood and metals, by one-fifth.

345. When the surfaces are worn, friction is, generally, diminished, within certain limits.—In wood, it is thus reduced, from one-half, to one-third of the pressure.

346. In woods, the friction is diminished, by crossing the fibres.—If, when the fibres are in the same direction, the friction is one-half the pressure; it is diminished, by crossing them to one-fourth.

347. Friction is greater, between surfaces of the same kind, than between those which are different.

348. While friction is diminished, by rendering the surfaces smooth; if this smoothness is carried too far, the friction may be increased, by the increased cohesion.

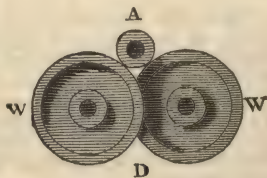
349. Anointing the surfaces with unctuous substances diminishes the friction—and the greater their consistence, the better.—Fresh tallow lessens the friction by one-half.

350. Supposing Vince to be correct, in stating that, diminishing the surface diminishes the friction, it may be increased, on the other hand, by the groove which will be produced.

351. When the friction is caused by one body rolling on another, it is directly proportional to the pressure; and inversely to the diameter.—That is, if a cylinder rolling along on a plane, have its pressure doubled; its friction, also, will be doubled. But if its diameter is doubled, the friction will be only half what it was.

352. FRICTION ROLLERS, or *friction wheels*, are applied to diminish the friction of axles, &c., their mode of action may be understood from fig. 127. If the axle A, instead of turning in a journal, plumbing block, &c., is made to turn on the friction wheels WW, the friction will be *nearly* as much less, than it would without them, as their diameters are greater than the diameters of their axles.—Since the pressure on the friction wheels is oblique, their effect is not quite as great, as the ratio between the wheels and their axles. These friction wheels may be made to turn on other friction wheels—

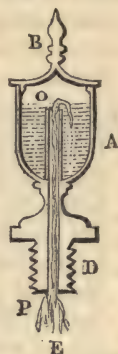
FIG. 127.



which will still further diminish the friction. If dust, &c., causes friction wheels to stop—which, not unfrequently, happens—a transverse groove is worn in their circumference, by the axle: and then they no longer revolve.

353. As a constant supply of lubricating matter is extremely important [349], in effecting a diminution of friction, various contrivances are used for the purpose. Among the best, is the cup, or urn A, fig. 128:—it contains a pipe O, extending from above the surface of the oil, to below a screw D—which fits in the aperture, through which the oil is to be introduced, into the journal, &c. If a few threads of cotton are inserted in the tube, and allowed to hang over the top of it, into the oil, they will act as a syphon; and will afford a small, but constant supply.

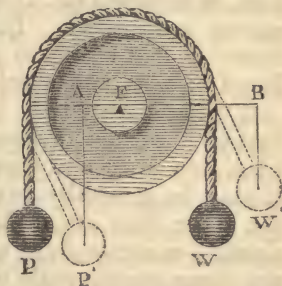
FIG. 128.



354. RIGIDITY OF CORDAGE.—Ropes are never quite flexible; they always, therefore, require some force to bend them:—this is so much power lost. A certain amount of the smallest thread may be kept in an horizontal position, by being held at one extremity—and hence the force required to bend it exceeds its weight. The effect of rigidity, in a rope, may be understood from fig.

FIG. 129.

129.—When the pulley is moved, the cord, on account of its inflexibility, tends to assume a position, approaching to that, indicated by the dotted lines. The leverage will, then, be changed; for, at first, the arms, to which both power and weight are attached, were equal to the radii of the pulley; but that arm of the lever which is next the power has become AF; and that which is next the weight, BF.—This is strictly true, only when the rope is quite inflexible; but it is clear, that all degrees of rigidity, consume proportional quantities of power, on account of the effort required to keep the rope in the proper position—which can very seldom, be completely effected.



355. Coulomb ascertained, that rigidity is dependent on the way in which the rope has been manufactured, on the degree of twist, &c.; and that, as far as the drum or pulley over which it passes is concerned, the resistance, from rigidity, is inversely as the diameter.

356. The resistance to the motion of bodies in fluids—water, or air, for instance—will be shown, in hydrostatics, to vary as the squares of the velocities. When the latter are high—as when locomotives move at the rate of 40 to 50 miles per hour—it becomes very serious.

CHAPTER IV.

HYDROSTATICS.

Objects of the Science ; and Division of the Subject, 1.—Pressure of Fluids—Hydrostatic Pressure, 6.—Hydrostatic Paradox, 16.—Bramah's Press, 20.—Hydrodynamic or Hydraulic Pressure, 31.—Surfaces of Fluids, 32.—Levels, 37.—Balloons, 40.—Specific Gravity, 46.—The Hydrometer, 53.—The Specific Gravity Bottle, 55.—Table of Specific Gravities, 65.—Floating Bodies, 67.—The Resistance of Fluids, 69.—Spouting Fluids, 75.—Motion of Fluids in Pipes, &c., 87.—Capillary Attraction, 96.—Hydraulics ; Vertical Water Wheels, 108.—Horizontal Water Wheels, or Turbines, 122.—Paddle Wheels of Steam Vessels, 135.—Screw of Archimedes, 137.—Screw Paddles, 139.—The Hydraulic Ram, 141.

1. OBJECTS OF THE SCIENCE ; AND DIVISION OF THE SUBJECT.—We have considered the laws which govern the action of solid bodies ; and are now to examine those which affect fluids. A fluid is a substance, the particles of which, are easily moved among each other. This facility of motion arises from the excess of that repulsive power, which (mech. 12) has been attributed to heat, and which modifies the attraction of cohesion.

2. Fluids are either “perfect”—as water ; or “imperfect,” having a certain degree of tenacity—as the syrup of sugar. Also, they are “non-elastic”—having so little elasticity as that it may be generally overlooked—as water ; or “elastic.”—If the latter, they are divided into those which are permanently elastic—as atmospheric air ; and those—termed vapours—which are “non-permanently elastic,” since they return to the fluid state, when reduced to the ordinary atmospheric temperatures.—Thus steam, at 212°, is as elastic, and as invisible as atmospheric air ; but, when cooled down below that point, it returns to the condition of water ; and, if it is in a state of minute division, remains suspended in the atmosphere—as cloud, mist, &c.

3 The science which treats of the equilibrium of non-elastic fluids, is termed *hydrostatics*.* That which treats of non-elastic fluids in motion is called *hydrodynamics*.† And that which treats of the construction of hydrodynamic machines, *hydraulics*.‡ The mechanical properties of elastic fluids are comprehended under the science which is termed *pneumatics*.

* *Hudōr*, water ; and *statos*, standing. Gr.

† *Hudōr*, and *dunamis*, force. Gr.

‡ *Hudōr*, and *aulos*, a pipe. Gr.

4. Fluids are said to be non-elastic, not because they have no elasticity whatever, but because they are compressed with difficulty, and only to a small amount.

5. That some fluids are incompressible, was, for a time, considered to be placed beyond doubt, by an experiment of the Florentine Academicians, who filled a globe of gold with water, and subjected it to a pressure, which flattened it a little at the sides, so as to diminish the quantity it was capable of containing:—the water issued through the pores of the metal, but was not sensibly compressed. It was, however, incorrectly inferred that the fluid suffered *no* compression whatever; and the researches of later philosophers have shown that it is really compressible.—If it is boiled—for the purpose of expelling the air which it contains—and is then placed in a tube, within the receiver of an air-pump, when the pressure of the air is diminished, its surface will be found to rise:—it was, therefore, compressed, by the air. And, if a bottle, containing fresh water, is, after being well corked, let down to a great depth in the sea, when it is drawn up again, the water, within it, will be found to have acquired a brackish taste:—this shows that the enormous pressure has driven in the cork—which could not have happened, unless the water inside had diminished in bulk, and allowed the sea water to enter, and mix with it.

It was ascertained by CErsted, that water loses the 0·000046th of its bulk for every additional pressure, equal to that of the atmosphere.

6. **PRESSURE OF FLUIDS—HYDROSTATIC PRESSURE.**—Fluids press equally, in all directions. For, if any number of vessels, are connected, at the bottom, by tubes, all of them will be filled, when water is poured into one.—The water, therefore, will be raised to, and sustained at the same height in all. Also, a vessel will empty itself, in the same time, by an aperture turned in any direction—provided it is of a given size, and at a given distance from the surface of the fluid. The use made by the ancients of aqueducts, has led many to suppose, erroneously, that they were ignorant of the property of fluids which causes them to rise to their own level.—But Pliny distinctly says, “that water ascends in a pipe to the height of the source from which it is derived.”*

7. This principle is used, in what are called *traps*—which assume a variety of forms, but are all intended to prevent the passage of bad smells, from sewers, &c. Their mode of construction may be understood from fig. 130. BAD is a bent tube, of which the space A always remains filled with fluid. Gases, &c., from the sewer, cannot pass into the

FIG. 130.



* Aqua in plumbo subit altitudinem exortûs sui. Plin. Nat. Hist. 31, vi. 31.

atmosphere, unless they descend through what is contained in A, which—since they are specifically lighter—is as impossible, as that a cork should sink, of its own accord, through water.

8. Fluids press with a force, proportional to the perpendicular height of the column above the point of pressure. Because the effect is due to the weight of the column of particles resting upon that point.

9. The great pressure, exerted at the bottom of deep seas, is evident, from the fact, that wood, sunk from 4,000 to 6,000 feet, becomes perfectly soaked, and will, no longer float.

10. The fine sand of an hour-glass, &c., seems to flow like a fluid:—but it follows very different laws. Since, whatever may be its height above the aperture, or whatever may be the pressure upon its surface, the velocity with which it passes out, is always the same. This may be proved, by filling a tube, having a small aperture at its lower extremity, with sand:—however strongly the upper surface of the latter is pressed, by a plug, &c., its escape will not be accelerated.

11. The pressure of a fluid, upon a surface, in a direction perpendicular to it, is equal to the area of the surface multiplied by the depth of its centre of gravity, below the surface of the fluid.—For, let AB, fig. 131, be the section of a given surface. The pressure, on this line, will be the sum of all the pressures, derived from the columns of water, over the points which form it:—for, since [6] fluids press equally in all directions, the pressure in a direction perpendicular to the surface, is exactly the same as the downward pressure. This

FIG. 131.

sum will be equal to the number of points, multiplied by the mean length of the columns. But HP, the depth of P, the centre of gravity of AP, is that mean length.—For, the surface of the triangle ABD, = the surface of the rectangle AEND.



Hence, the sum of all the columns of water, will be the downward pressure—whether we consider them all of a mean height HP; or suppose their heights to gradually increase, from 0, at A, to BD, at B.

12. If AB is not a right line, the same reasoning will still be true. And it will hold, not only with reference to the various lines of the given surface, taken separately, but also to the aggregate of the lines—or the given surface itself; the depth of the centre of gravity of which, will be the mean height of all the columns—the shortness of some, being compensated for, by the greater length of others.

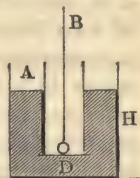
13. Hence the pressure, on the side of a cube, is half the pressure on its base.—For the surfaces of the base and side are equal; but, the centre of gravity of the one, is twice as deep

below the surface of the fluid as that of the other. Hence, also, the pressure of the bottom of a vessel, which diminishes in size, from the base upwards, may be far greater, than the weight of the fluid, it contains.

14. The upward pressure of fluids, against a surface, may be illustrated, by the apparatus, fig. 132. Let H, be a vessel, containing water. Let A, be a hollow cylinder, to

FIG. 132.

the ground end of which, a plate D, is accurately fitted. If the plate is kept pressed against the end of the cylinder, while the latter is immersed in the water, and the string B is then let go, not only will D not fall down—so as to allow water to enter A, but it will remain unmoved: and will, even, support any weight which—along with the plate itself—does not exceed the weight of the water, that would enter A, if the plate were taken away.—Whether there is water in B, or not, the pressure, which would have supported it, is still in action. If water is poured into A, until the fluid is nearly at the same level inside and outside of it, the plate will fall.



The same fact may be shown, by fitting a *thin* plate of glass, water-tight, to a cylindrical vessel, open at both ends.—If the cylinder is, then, either filled with water, or fully immersed in it, the glass plate will be broken:—this will not happen, however weak the plate may be, if the fluid is kept at the same height, inside, and outside—even though mercury is used instead of water.

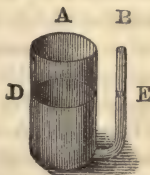
15. It is easy, from what has been said, to estimate the pressure, exerted by the water in a canal, &c., against the gate of a lock, &c.

EXAMPLE.—Let the two gates of a lock be each 12 feet wide; and let the level of the water be 8 feet above their lower extremities. Taking a cubic foot of water at 1000 oz. = 63 lbs. nearly, the pressure against each gate will be $12 \times 8 \times 4 \times 63 = 24,192$ lbs. = 10·8 tons.

16. HYDROSTATIC PARADOX.—“An indefinitely small quantity of fluid may be made to balance one that is indefinitely large.”—Let the vessel A, fig. 133, and the tube B, which are connected together, at their lower extremities, be filled

FIG. 133.

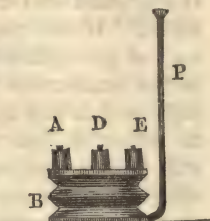
with water to D, and E. The small quantity in B, keeps the, comparatively, large quantity, in A, in equilibrio—since, the least change in one, will cause motion in the other. The pressure communicated by B, causes an upward pressure in A, which is capable of supporting a quantity of fluid, equal to its base, multiplied by the average height [11] of the columns,



resting upon it—This pressure will sustain, not only the fluid in A, but anything which may be made to supply its place. For, if we take away all the fluid which is above any horizontal stratum of particles; and replace it by a board, &c.—to receive the pressure, we may put so much weight on the board, as will be equal to that of the water which has been removed.

17. *The Hydrostatic Bellows* B, fig. 134, is constructed on this principle. It consists of two boards, connected by strong leather—something like the ordinary bellows. If water is poured into the tube, P, which is attached to it, A, D, and E will be raised—provided their weight does not exceed that of the column of water, which may be considered as replaced by the upper board.

FIG. 134.



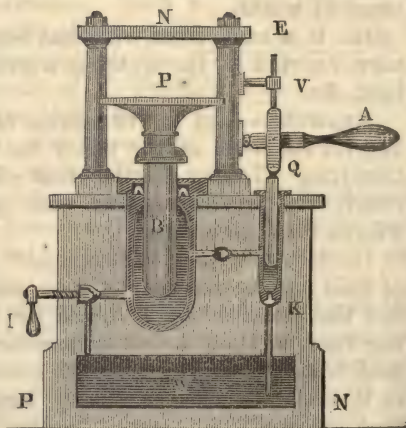
18. A person standing on the bellows, may easily lift himself, by blowing into the tube:—for it is of no consequence, what the fluid is, from which the pressure is derived.

19. We may even replace the fluid, in P, by a solid piston, &c.—a pressure on which will produce the same effect as would be derived, from a column of fluid.

20. *BRAMAH'S PRESS*.—The facts, which I have just explained, are used in the construction of a very powerful hydraulic press, generally called after Bramah, its first constructor. It may be understood from fig. 135:—

FIG. 135.

so much of the exterior is supposed to be removed, as will be sufficient to show its internal arrangement. B, is a large piston, working water-tight in a very strong vessel: and, as the tendency to leakage—from the great pressure—is considerable, the packing of leather, placed around it, is so contrived, that the greater the pressure, the more tightly it embraces B, and the more completely it confines the water. A small pump Q, worked by the handle A, raises water from the cistern W, and forces it under B.—Anything, placed between P and N will, as B rises, be powerfully compressed. The rod EQ, is kept in a perpendicular position, by a guide at V. The water flows back again into W, on turning the handle H: and B immediately descends.



21. The effect of such a machine, is equal to the pressure on the plunger of the pump, multiplied by the square of the diameter of the large piston, and divided by the square of the diameter of the plunger.

EXAMPLE.—The larger piston is 7 inches : the plunger of the pump, $\frac{1}{2}$ an inch in diameter ; the pressure on the plunger, 2 cwt. What is the hydraulic pressure upon the large piston ?

The required pressure = $\frac{2 \text{ cwt.} \times 7^2}{\frac{1}{2}^2} = 392 \text{ cwt.} = 19 \text{ tons, } 12 \text{ cwt.}$

Friction, at the packing, destroys a very considerable amount of the power.

22. The enormous effects obtained from the hydrostatic press, have given rise to many speculations, as to its more extensive application to useful purposes. But, it must never be forgotten, that no machine can give back *more* power than it receives, (mech. 152,) since none can generate power. The hydraulic press is not an exception to this law :—since, if by means of it, we can raise a great weight, we can do so, only at the expense of velocity. For, in proportion as the press is powerful, its effect will be slow ; because, just to the same extent, will the size of the force pump—compared with that of the larger vessel, which it supplies—be diminished ; and through, just so much the greater distance, must the hand, &c., which works the pump, travel, to produce the required result. Hence, if we are able, without such an apparatus, to lift a given weight through a certain space, in a given time ; to lift by means of it 1,000 times that weight, through the same space, we shall require a period 1,000 times as long.

23. It is not, in reality, surprising, that a small quantity of water, fig. 133, should balance a very large one ; since what is in the tube resists the pressure of that portion, only, which is next to it : the vessel itself, which contains the large quantity, supports the pressure of the remainder.

24. The hydraulic press is more convenient than the screw ; because, as the friction between solids and fluids is very trifling, it wastes, *comparatively*, but little force.

The principle of the hydraulic press, causes a bottle to burst when it is corked, unless some air is left above the fluid :—without this, a slight blow on the cork, would generate a very great pressure within the bottle.

25. The hydraulic press is often used, to diminish the bulk of hay, cotton, and other light goods, for exportation. It has been proposed, also, as a means of drying the peat of our bogs, and rendering it, by its great density, capable of imparting a stronger, and more permanent heat.—But the expense of the apparatus, and the slowness with which it works, have hitherto prevented its general adoption.

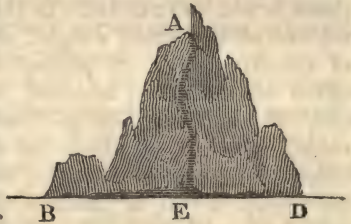
26. Its principle is applied to the proof of steam boilers, &c.

—They are filled with water, and connected with a force pump. If any part of them is too weak, it will give way, before the safety valve—loaded more than it is intended to be, when the boiler, &c., is in use—opens and allows the water to escape. It ought, however, to be borne in mind, that the very testing of the boiler, may cause such a strain as will weaken it considerably. When it is proved with a force pump, there is no danger to the workmen, since the weak part merely opens, and water gushes out, the effect taking place too slowly, and the action being exerted through too small a distance to produce an explosion:—the result would be very different, were steam pressure employed.

27. Some remarkable consequences, follow from the property of fluids, which is, at present, under consideration. Thus, let BAD, fig. 136, represent the section, made by a vertical plane,

FIG. 136.

AE—of considerable depth, but of trifling thickness, and spread out below, so as to cover a large horizontal surface BD. Should this fissure be filled with water, the upward pressure may become so enormous, as to upheave vast quantities of earth, rock, &c. There is little doubt, that some very important operations of nature, are due to this cause.



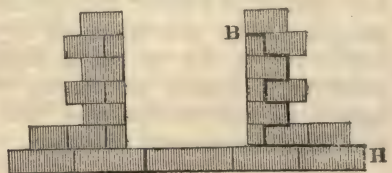
28. When a flood occurs in a river, the danger to be apprehended, is not so much the throwing down of the bridge, by the momentum of the water, as its being *blown up*, by a pressure from below:—that is, by a pressure in a direction, in which it is weak—the resistance, which it exerts, arising only from the weight and cohesion of its materials. If the water reaches to

FIG. 137.



FIG. 138.

29. If a crevice BH, fig. 138, is formed behind the wall of a canal lock, and filled with water; the latter, when the lock is emptied, exerts an outward pressure, equal to the product of the



surface of that part of the wall—behind which it is—and the depth of its centre of gravity, below the highest part of the fluid [11]. This may, very easily, cause the wall to be forced out.

30. If a crevice is formed under a canal bank, &c., and filled with water; it may gradually increase, to such an extent, that the upward pressure will be much greater than the weight and cohesion of the materials of the bank, can withstand.—It will, therefore, be forced upwards: and the effect, to those who do not know its cause, becomes a source of great astonishment. The smallness of the quantity of water, contained in the crevice, will not be any source of security to the bank—since the least quantity, under certain circumstances, is capable of exerting any amount of pressure [16].

31. **HYDRODYNAMIC, OR HYDRAULIC PRESSURE.**—The pressure of fluids, as well as that of solids [mech. 338], is diminished by motion.—Hence pipes occasionally burst, when they become choked, so as no longer to allow the fluid to pass. The more rapidly water flows, the less it presses against the sides of the pipe, &c. This fact may be illustrated, by the apparatus represented fig. 139. It consists of a vessel having different horizontal sections, and tubes connected with them. The section at E being larger than that above, the velocity of the fluid passing there is, as we shall find, greater also: and its pressure being augmented by decrease of velocity, it will ascend in the tube DT, higher than the fluid in the vessel—the pressure in the lower part of DT being more than enough to counterbalance that of the atmosphere above. The section at P being smaller than that of the upper portion of the vessel, the velocity of the fluid will be greater; but its lateral pressure being less, the fluid will not ascend in QF so high as in the vessel. Lastly, the section at H being very small, the velocity of the fluid is comparatively very great, and its pressure is so diminished, as to have become *negative*—that is, insufficient to counterbalance the pressure of the atmosphere above:—consequently, fluid will rise from the vessel V; and, if the tube ZX is not too long, it will enter the larger vessel at H and be discharged at K, the current being perceptible if the fluid in V is coloured.

FIG. 139.

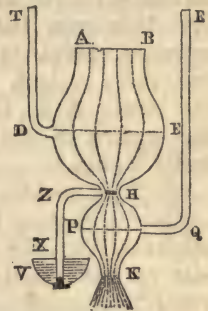


FIG. 140.

32. **SURFACES OF FLUIDS.**—The surface of a fluid, if at rest, is always horizontal.—Otherwise two particles, E and H, fig. 140, would remain in equilibrio, although the pressure, exerted by one



EXAMPLE.—What distance is visible from a height of 1,760 feet?

$$1,760 \text{ feet} = 21,120 \text{ inches.}$$

$$\sqrt{\frac{21,120}{8.004}} = \sqrt{2638.68} = 51.36 \text{ miles.}$$

It is evident, that no part of the earth's surface, more distant than D, fig. 142, can be seen from T.

36. Knowing the height of an object, we can ascertain the distance, from which it can be seen. For, the required number of miles is equal to the extent of horizon, visible from its summit.—Because if D, fig. 142, is visible from T, T will evidently be visible from D.

EXAMPLE.—At what distance will a light, 125 feet above the level of the sea, become visible? 125 feet = 1,500 inches.

$$\sqrt{\frac{1,500}{8.004}} = 13.7 \text{ miles.}$$

It is evident, that B would be visible from T, and *vice versa*. And the distance between B, and T, is equal to the extent of the visible horizon at B, plus the visible horizon at T.

Refraction has not been taken into account in these calculations.—But, it is found, that the distance at which an object can be seen, with refraction, is to the distance, at which it could be seen without it, as 14 is to 13. When, therefore, the distance is considerable, refraction must not be neglected.

37. LEVELS depend on the fact, that the surface of a fluid, at rest, is horizontal. A “level” is an instrument, by means of which, it may be ascertained whether, or not, a given surface is parallel with the horizon. It generally consists of a glass tube, AB, fig. 143,

FIG. 143.



hermetically* sealed, at both ends; and filled, except a small bubble, with some fluid :—the latter is, generally, alcohol because it moves easily, and does not freeze.—If either end of the tube is higher than the other, the air, in the bubble, will ascend towards it. When the tube is perfectly horizontal, the bubble will rest between the extremities; and, if the tube is slightly arched upwards, it will remain exactly at the centre D.

The glass tube is, very frequently, enclosed in a brass case, having an aperture which allows the bubble to become visible, when its under side rests on a truly horizontal surface.

38. If two different fluids are placed, carefully, in the bent

* The aperture of a tube, &c., is said to be “hermetically” sealed, when it is filled up, by fusing to its edges, enough of the substance of which the tube is made, to close it completely.

tube AHB, fig. 144—so that one of them, only, shall be in the part AH, and the other, only, in the part BH—since the two parts are connected at H, DO, and EO, the respective heights of the fluids, will be, inversely, as their densities. For the two pressures counterbalance each other. But, to produce equilibrium—if their densities are unequal—the lesser density of one must be compensated for, by its greater height.

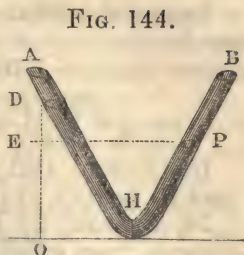
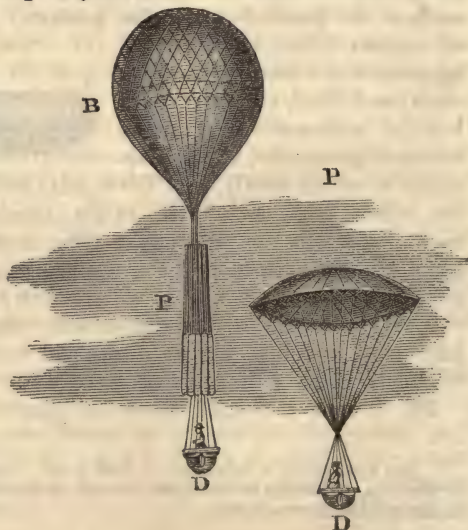


FIG. 144.

39. The ascent of a body in a fluid, of greater density than itself, arises from the upward pressure, which the weight of the body is not sufficient to overcome. For, before the body was immersed, the upward pressure supported a quantity of fluid of equal bulk; but of greater weight. Some of this pressure remains uncounteracted, and must, therefore, produce motion. —But the body will not ascend, if it is placed on the bottom, in such a way, as that no fluid will be under it. Fishes are nearly of the same specific gravity as the fluid in which they swim: and ascend, or descend, with facility by altering the bulk of an air vessel contained within them, by the action of muscles. If this vessel is perforated, they sink to the bottom. Flat fishes have no air vessel. When fish are brought up suddenly from great depths, the air vessel swells so much, that they cannot again sink—and it sometimes even bursts. The air contained in the air vessel of fishes taken near the surface is nitrogen almost in a state of purity.

FIG. 145.

40. BALLOONS. The property of fluids, just noticed, causes balloons to rise in the air. Their upward motion being due to that law, which makes a cork ascend in water. They are of two kinds, the “fire” and “gas balloon.” Each consists of a bag of silk, B, fig. 145, or some other light material, covered with a netting, from which is suspended, either the car D, containing the aeronaut, or the parachute P.



—When the latter is used, the car is attached to it. The silk bag, &c., is filled with a fluid, lighter than the atmosphere at the surface of the earth.

41. When it is a fire balloon, this fluid is common air, rarified—and therefore, rendered less dense—by a furnace, placed in the car. The rarified air ascends into the machine, and causes it to be lighter than that which surrounds it.

When it is a gas balloon, it is inflated with hydrogen, or coal gas. If the apparatus is small, the hydrogen, &c., must be freed from the water, with which it is combined, by passing it through a tube containing pieces of fused chloride of calcium—a substance which, as we shall see hereafter, has a strong tendency to unite with water. Without this precaution, the gas would be too heavy.

42. The balloon must not be quite filled with gas: since it is necessary to leave room for the expansion, consequent on the pressure around it being diminished, by its ascent into the higher regions—where the atmospheric air is more rare, and, therefore, exerts less pressure.

43. The aeronaut carries up bags, filled with sand: and gradually empties them when he desires to ascend higher:—the smallness of their particles prevents them from doing any mischief, notwithstanding the great height from which they fall. When he wishes to descend he allows the gas to escape, by a valve at the top—since, the air within, being lighter than that which is outside, cannot *descend*:—hence the tube by which the balloon was inflated, may be left open without the gas escaping.

44. Balloons have been rarely used except for experiment: sometimes, however, they have been applied, by armies, to the purpose of reconnoitring.—Their great size, the difficulty of guiding, or controlling them, and the danger which attends their use, will prevent, in all probability, even at any future period, their general adoption. The fire balloon is particularly hazardous, and has, more than once, caused the destruction of life. Sometimes, gas balloons, also, have been the source of accident:—instances have occurred, in which they have been burst, by the expansion of the gas; and the unavoidable [43], distance of the valve has, in some cases rendered it unmanageable, from imperfection in the machinery.

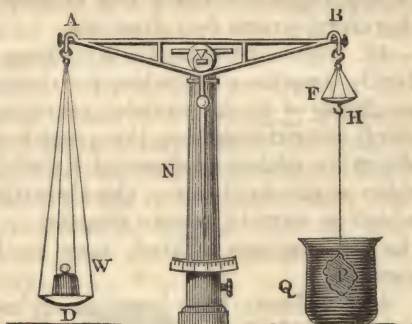
45. The *parachute* P, fig. 145, has been occasionally employed to lessen the danger; or for experiment. While attached to the balloon, it remains closed: but, on being separated from it, expands, during its descent—which, at first, is extremely rapid—and then it resembles an umbrella. The great peril, attending its use, arises from its violent oscillation, and from its being likely to become entangled, in the roofs of buildings, trees, &c.—Should the oscillation become such as would make

it overset, it would immediately close up, and the descent would, after that, be made with frightful velocity [mech. 58]. Under ordinary circumstances, a maximum speed is obtained, soon after it has expanded—the increased resistance of the air, destroying the increase of velocity, generated by the force of gravity.

46. SPECIFIC GRAVITY is the weight of any body, compared with that of another, considered as a standard. It is usual to compare the density of solids and fluids, with that of an equal bulk of distilled water, taken as 1, or 1000 : and of gases, with an equal bulk of atmospheric air. If the density of gases and vapours were compared with that of water, the terms of the resulting fraction would be inconveniently large.

47. We may take the specific gravity of a solid, heavier than water, by weighing it first in air, by means of the balance, fig. 146, and then ascertaining how much weight it loses, when immersed in water, contained in the vessel Q.—

FIG. 146.



The weight lost will be that of an equal bulk of water; and if it is divided into what the body weighed in air, the result will be the required specific gravity. Thus, if the weight of anything in air, is three pounds, and, in water, two pounds, the *equal* bulk of that fluid, which it displaces, weighs one pound. And $\frac{3}{2} = 1.5$ expresses its weight, compared with that of water—or, in other words, its specific gravity. It is three times as heavy as water, since the pressure, which supported the water it displaced, is sufficient to sustain, only one-third of its weight. It is evident that the specific gravities of two bodies are inversely as the weights they lose when equal weights of them are immersed. Bodies are, light or heavy, not on account of their *absolute* weight, but of their *specific* gravity.—Thus, a pound of wool is a light, but an ounce of lead a heavy body : though the former is, actually the heavier.

48. Since a body loses, in water, a weight, equal to that of a mass of the fluid of the same bulk, we are not to be surprised that enormous blocks of stone, &c., are rolled along by torrents :—for, when immersed in water, they become comparatively light : and a, proportionably, smaller force, is sufficient to move them. On the other hand, a heavily laden vessel may float with safety in the sea, but may sink when it enters the fresh water of a river—in which it will become relatively heavier.

49. If the specific gravity of a body, lighter than water, is

to be determined, we must find how much additional weight it requires to sink it; and its specific gravity will be equal to the quotient, obtained by dividing the sum of its weight in air and the weight added to sink it, by its weight in air.—Let us suppose that it requires twice its own weight, to sink it. Then $\frac{1}{3}=0.33$, &c., will express its weight, compared with that of water. That is, water is three times as heavy: and the pressure, which supported the water, is capable of supporting three times its weight.

50. When a body is immersed in a fluid, lighter than itself, it will displace a quantity, equal to its bulk, but less than its weight; if, in a fluid, heavier than itself, it will displace a quantity, equal to its weight, but less than its bulk.

51. A knowledge of these facts, enabled Archimedes, the famous mathematician, to detect the dishonesty of a goldsmith to whom Hiero, king of Syracuse, had given a quantity of gold, for the manufacture of a crown. Hiero distrusted the goldsmith, and communicated his suspicions to Archimedes, that he might remove, or change them into certainty. The philosopher himself was, for some time, unable to solve the problem. But, remarking that, on entering a bath, he caused the water to overflow, a simple mode of arriving at the truth, flashed across his mind; and, delighted at the discovery, he cried out, in ecstasy, “I have found it; I have found it.”—He saw, at once, that a certain weight of gold—the heaviest substance then known—must displace less water, than the same weight of any other body. On making the experiment, with the crown, furnished by the artist, he discovered that its bulk was greater than it should be, if made of pure gold. This fact once known, the amount of alloy could easily be discovered—but, by methods, which do not belong to our present purpose.

52. When a body is soluble in water, its specific gravity may, sometimes, be conveniently found, by immersing it in a fluid of known specific gravity, in which it is not soluble.

53. THE HYDROMETER, used for taking the specific gravity of fluids, is founded on the fact, that the lighter a solid is, compared with the fluid in which it is immersed, the less it will sink. It consists of a graduated stem D, fig. 147; a bulb A, and a smaller bulb B, containing mercury—which, depressing the centre of gravity of the instrument, causes it, when immersed in a fluid, to assume an upright position.—The graduation of the stem shows the extent to which the hydrometer sinks, in a given fluid; and, consequently, the specific gravity of the latter. When it is intended to be used with liquids that are not corrosive, it may be of brass—to render it less easily injured.

FIG. 147.



54. It has been found that, if, on account of dirt, &c., the surface of the hydrometer does not moisten freely with the fluid, it may stand, in it, two, or three degrees higher, or lower, than it ought.

55. THE SPECIFIC GRAVITY BOTTLE also, is employed for taking the specific gravity of fluids, &c. It consists of a light glass bottle, which holds a given quantity—suppose 720 grains—of distilled water, at a certain temperature—generally, 60° . If this bottle, when counterpoised, and filled with another fluid, at the same temperature, weighs, for example, 550 grains; the density of that fluid must be to the density of water: 550: 720. And water being unity, its specific gravity will be represented by $\frac{550}{720} = 0.7639$.

56. We ought, if possible, to take the specific gravity of fluids, at the temperature of 60° .—If we compare specific gravities, obtained at various temperatures, we must allow for the contraction, or expansion, due to the difference.

57. The specific gravity of solids, also, may be ascertained, by means of the specific gravity bottle.—Suppose the specific gravity of a given earth is to be found. If the bottle holds 720 grains, we place it in 360 $\left(= \frac{720}{2} \right)$ grains of water: and then so much of the earth to be examined, as, along with the distilled water, will completely fill it.—Were the earth, and the water, of the same specific gravity, the contents of the bottle would now weigh 720 grains. But, let them, instead of this, weigh 900 grains.—It follows, that a quantity of the earth, equal in bulk to half the interior of the bottle, weighs 540 grains; while the same bulk of water weighs but 360 grains. The density of distilled water is, therefore, to that of the earth :: 360: 540; and the specific gravity of the earth is $\frac{540}{360} = \frac{3}{2} = 1.5$.

58. The specific gravity of a gas may be taken, by means of a light glass globe, which is to be carefully weighed—or, to avoid the necessity of making allowance for the changes which might occur, during the course of the experiment—counterpoised, while full of air, with a similar globe. It is then to be exhausted, and the difference of its weight is to be ascertained.—This will give the weight of the atmospheric air contained in it. While still empty, it is to be screwed on a receiver, containing the gas to be examined, and being filled with the latter, is to be again, weighed. The difference between its weight, when empty, and when full of the gas, will be the weight of the gas—which may be compared, with what has been ascertained to be the weight of an equal bulk of common air.

59. The gas, before being weighed, must be either perfectly dried, by transmitting it through chloride of calcium; or it must be perfectly saturated with moisture, by allowing it to stand over water—and, then, the correction for the aqueous vapour, it contains, may be made from the following table, which shows what portion of its total bulk, is due to the vapour:—

Degrees.	Amount of aqueous vapour, in terms of the bulk.	Degrees.	Amount of aqueous vapour, in terms of the bulk.
40 . . .	0·00933	61 . . .	0·01923
41 . . .	0·00973	62 . . .	0·01980
42 . . .	0·01013	63 . . .	0·02050
43 . . .	0·01053	64 . . .	0·02120
44 . . .	0·01093	65 . . .	0·02190
45 . . .	0·01133	66 . . .	0·02260
46 . . .	0·01173	67 . . .	0·02330
47 . . .	0·01213	68 . . .	0·02406
48 . . .	0·01253	69 . . .	0·02483
49 . . .	0·01293	70 . . .	0·02566
50 . . .	0·01333	71 . . .	0·02653
51 . . .	0·01380	72 . . .	0·02740
52 . . .	0·01426	73 . . .	0·02830
53 . . .	0·01480	74 . . .	0·02923
54 . . .	0·01533	75 . . .	0·03020
55 . . .	0·01586	76 . . .	0·03120
56 . . .	0·01640	77 . . .	0·03220
57 . . .	0·01693	78 . . .	0·03323
58 . . .	0·01753	79 . . .	0·03423
59 . . .	0·01810	80 . . .	0·03533
60 . . .	0·01866		

60. The specific gravity of a gas, at any one temperature, may be deduced from that, at any other. For, as we shall find hereafter, it expands the $\frac{1}{492}$ nd of its volume at 32° Fahrenheit, for every degree it increases in temperature.

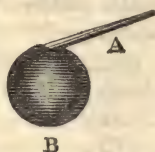
61. The change in specific gravity, made by altering atmospheric pressure, is easily ascertained: since the volume is inversely as the pressure.

62. The specific gravity of a gaseous compound may be obtained, by adding together the specific gravities of the volumes of the component parts, and dividing the sum by the number of volumes in the compound.—Thus, nitrous oxide consists of two volumes nitrogen ($2 \times 0\cdot976$) = $1\cdot952$ } and one volume oxygen = $1\cdot106$ } = $3\cdot058$. But as the three volumes of the elements—being condensed during combination—form but two volumes of the compound, the specific gravity of one volume of the latter is $\frac{3\cdot058}{2} = 1\cdot529$: which is the specific gravity of nitrous oxide.

63. The specific gravity of a vapour—that of alcohol, for

example—at a given temperature, may be obtained, by means of a light bulb of glass B, fig. 148, having a neck A, drawn out very fine, in a lamp. The bulb being heated, its tube is to be immersed in the alcohol:—the partial vacuum, produced within it by cold, will cause the atmospheric pressure to force in some alcohol. It is then to be placed in a fluid, which boils at a higher temperature than that, to which the vapour must be raised:—chloride of zinc, the boiling point of which is very high, answers, for the purpose, in some cases; but, in others, it will be necessary to use *fusible metal*, which is made by melting together eight parts, by weight, of bismuth, three of tin, and five of lead. The bulb, and the fluid, in which it is immersed, should now be raised to the required temperature—ascertained by a thermometer; and, when nothing but vapour remains in the bulb, its capillary neck is to be hermetically sealed, with the flame of a lamp urged by the blow-pipe. It is, then, to be cooled, and weighed:—the vapour will be condensed; but this is of no consequence, since there will be nothing else in the interior of the bulb. The contents of the latter, in cubic inches, &c., may be found, by breaking off the fine point of the tube under the surface of mercury, and allowing the whole interior to be filled with that fluid—which is, then, to be poured out, and measured. If, besides the mercury, a bubble of air is perceived in the bulb; we must allow for it, since it was present, with the vapour examined.

Fig. 148.



64. In this experiment, the pressure of the air, &c., are to be taken into account [61].

65. TABLE OF SPECIFIC GRAVITIES.—

Agate,	2.590
Alum,	1.714
Amber, from	1.065 to 1.100
Ambergris, from	0.780 to 0.926
Amethyst, common,	2.750
— Oriental,	3.391
Amianthus from	1.000 to 2.313
Arragonite,	2.900
Asphaltum, or Mineral Pitch, from	0.905 to 1.650
Barytes, Sulphate of, from	4.000 to 4.865
— Carbonate of, from	4.100 to 4.600
Basalt, from	2.421 to 3.000
Bees' Wax,	0.964
Beryl, Oriental,	3.549
— Occidental,	2.723
Blood, Human,	1.053
Borax,	1.714
Butter,	0.942

Calcareous Spar, from	2·620 to 2·837
Camphor,	0·988
Caouchouc,	0·933
Cornelian, Speckled,	2·613
Chalcedony, common, from	2·600 to 2·65
Chalk, from	2·252 to 2·657
Chrysolite,	3·400
Crystalline lens of the Eye,	1·100
Coals, from	1·020 to 1·300
Copal,	1·045
Coral, Red, from	2·630 to 2·857
—— White, from	2·540 to 2·570
Corundum,	3·710
Diamond, Oriental, colourless,	3·521
—— coloured, from	3·523 to 3·550
—— Brazilian,	3·444
—— coloured, from	3·518 to 3·556
Dolomite, from	2·540 to 2·830
Dragons' Blood (a resin),	1·204
Emerald, from	2·600 to 2·770
Euclase, from	2·900 to 3·300
Fat of Beef,	0·923
„ Hogs,	0·936
„ Mutton,	0·923
„ Veal,	0·934
Felspar, from	2·438 to 2·700
Flint, Black,	2·582
Fluor spar, from	3·094 to 3·791
Gamboge,	1·222
Garnet, precious, from	4·000 to 4·230
—— common, from	3·576 to 3·700
Glass, Crown,	2·520
—— Green,	2·642
—— Flint, from	2·760 to 3·000
—— Plate,	2·942
Granite, from	2·613 to 2·956
Gum Arabic,	1·452
Gypsum, compact, from	1·872 to 2·288
—— crystallized, from	2·311 to 3·000
Heliotrope, or Bloodstone, from	2·629 to 2·700
Honey,	1·440
Honeystone, from	1·560 to 1·666
Hornblende, common, from	3·250 to 3·830
—— basaltic, from	3·160 to 3·333
Hornstone, from	2·533 to 2·810
Hyacinth, from	4·000 to 4·780
Jasper, from	2·358 to 2·816
Jet,	1·300
Indigo,	1·009
Ironstone from Carron,	3·281
—— from Lancashire,	3·573

Isinglass,	1·111
Ivory,	1·825
Lard,	0·947
Limestone, compact, from	2·386 to 3·000
Magnesia, native, hydrate of,	2·330
———— carbonate of, from	2·220 to 2·612
Malachite, compact, from	3·572 to 3·994
Marble, Carrara,	2·716
———— white Italian,	2·707
———— black veined,	2·704
———— Parian,	2·560
Mastic,	1·074
Melanite, or Black Garnet, from	3·691 to 3·800
Mica, from	2·650 to 2·934
Milk,	1·032
Myrrh,	1·360
Naptha, from	0·700 to 0·847
Nitre,	1·900
Obsidian, from	2·348 to 2·370
Essential Oils—	
Amber,	0·868
Anise Seed,	0·986
Carraway Seed,	0·904
Cinnamon,	1·043
Cloves,	1·036
Fennel,	0·929
Lavender,	0·894
Common Mint,	0·898
Turpentine,	0·870
Wormwood,	0·907
Expressed Oils—	
Sweet Almonds,	0·932
Codfish,	0·923
Filberts,	0·916
Hempseed,	0·926
Linseed,	0·940
Olives,	0·915
Poppy Seed,	0·939
Rape Seed,	0·913
Walnuts, from	0·923 to 0·947
Whale,	0·923
Opal, precious,	2·114
—— common, from	1·958 to 2·114
Opium,	1·336
Orpiment, from	3·048 to 3·500
Pearl, Oriental, from	2·510 to 2·750
Peat, from	0·600 to 1·329
Pitchstone, from	1·970 to 2·720
Plumbago, from	1·987 to 2·400
Porcelain, from China,	2·384
———— from Sevres,	2·145

Porphyry, from	2·452 to 2·972
Pumice Stone, from	0·752 to 0·914
Quartz, from	2·624 to 3·750
Realgar, from	3·225 to 3·338
Rock Crystal, from	2·581 to 2·888
Ruby, Oriental,	4·283
Sapphire, Oriental, from	4·000 to 4·200
Sardonyx, from	2·602 to 2·628
Scammony of Smyrna,	1·274
—— of Aleppo,	1·235
Schorl, from	2·922 to 3·452
Serpentine, from	2·264 to 2·999
Shale,	2·600
Silver Glance, from	5·300 to 7·208
Slate, drawing,	2·110
Smalt,	2·440
Spermaceti,	0·943
Spodumene, from	3·000 to 3·218
Stalactite, from	2·323 to 2·546
Steatite, from	2·400 to 2·665
Stone—	
Bristol, from	2·510 to 2·640
Cutler's,	2·111
Grinding,	2·142
Hard,	2·460
Paving, from	2·415 to 2·708
Portland,	2·496
Rotten,	1·981
Sugar,	1·606
Talc, from	2·080 to 3·000
Tallow,	0·941
Topaz, from	4·010 to 4·061
Tourmaline, from	3·086 to 3·362
Turquoise, from	2·500 to 3·000
Ultramarine,	2·360
Water, Distilled,	1·000
—— of Dead Sea,	1·240
Wine—	
Bordeaux,	0·993
Burgundy,	0·991
Champagne,	0·998
Constance,	1·081
Claret,	0·994
Malaga,	1·022
Moselle,	0·916
Port,	0·997
Rhenish,	0·999
Wood—	
Alder (green),	0·857
—— (dry),	0·500
Apple Tree,	0·793

Wood, *continued*—

Ash (green),	0·904
— (dry),	0·644
Bay Tree,	0·822
Beech (green),	0·982
— (dry),	0·590
Box, French,	0·912
— Dutch,	1·328
Brazilian, Red,	1·031
Campeachy,	0·913
Cedar, Wild,	0·596
— Palest,	0·613
— Indian,	1·315
— American,	0·561
Cherry Tree,	0·715
Citron,	0·726
Cocoa,	1·040
Crab Tree,	0·765
Cork,	0·240
Cyprus, Spanish,	0·644
Ebony, American,	1·331
— Indian,	1·209
Elder Tree,	0·695
Elm,	0·671
Filbert Tree,	0·600
Fir, Male,	0·550
— Female,	0·498
Hazel,	0·600
Jasmin, Spanish,	0·770
Juniper,	0·556
Lemon Tree,	0·703
Lignum Vitæ,	1·333
Linden or Lime Tree,	0·604
Mastic Tree,	0·849
Mahogany,	1·063
Maple (green),	0·904
— (dry),	0·659
Medlar,	0·944
Mulberry, Spanish,	0·897
Oak, heart of, sixty years old,	1·170
Olive Tree,	0·927
Orange Tree,	0·705
Pear Tree,	0·766
Pine (green),	0·890
Pine (dry),	0·555
Plum Tree,	0·785
Pomegranate,	1·351
Poplar,	0·383
— White, Spanish,	0·529
Quince,	0·705
Sassafras,	0·482

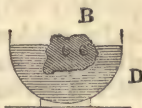
Vine,	1·327
Walnut,	0·681
Willow,	0·585
Yew, Dutch,	0·788
— Spanish,	0·807
— Knot, sixteen years old,	1·760
Woodstone, from	2·045 to 2·675
Zeolite, from	2·073 to 2·718

The specific gravity of the elementary bodies, and of their most important combinations, will be given, when I treat of them, in Chemistry.

66. The specific gravity of many substances is much greater than, on account of the air contained in their pores, it seems to be.—That of the raspings of lime-wood was found so high as 1·13; of fir, 1·16; of oak, 1·27; and of beech, 1·29. And Rumford's experiments lead to the conclusion, that the heavy part of all woods have a specific gravity of 1·5. If, therefore, the air it contains has been expelled by water [9], wood will sink.

67. FLOATING BODIES.—When a body floats on a fluid, the centre of gravity of the body, and of the fluid displaced, is in the same vertical line. For, whether it is the fluid displaced, or the body, that is supported by the upward pressure, the latter may be considered as concentrated at the centre of gravity.—Let C, fig. 149, be the centre of gravity of the fluid; and C' the centre of gravity of the floating body—not in the

same vertical line as C. The pressure of the fluid, before it was displaced, was counterbalanced by equal and opposite pressures—those at each side of C; which must, therefore, be equal. For a similar reason, as the body is at rest in the fluid, the pressures at each side of C', also, must be equal. But it is evident that, if half the entire pressure was exerted in supporting the water displaced, at one side of C, more or less than half, must be exerted in supporting that part of the body at the same side of C'.—Hence, there cannot be equal pressures at each side of C', unless C and C' are found in the same line, perpendicular to the horizon.



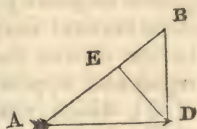
68. When a body floats on a fluid, the part out of the fluid is to the whole, inversely, as the specific gravity of the body.—That is if, for instance, water has twice the specific gravity of the body, only one half of the latter will be immersed. For the more dense it is, the more of it must be immersed: since the greater must be the quantity of water displaced, that the upward pressure may support it; and *vice versa*.

69. THE RESISTANCE OF FLUIDS arises from their tenacity, their inertia, and the friction of their particles against the solid body. The resistance of fluids, to a body moving in them,

varies as the square of the velocity of the body.—If, for example, this velocity is increased, so that it will become three times as great, three times the number of particles of the fluid will be struck by it, in the same time; and each of them, with three times the force.—The resistance will, therefore, be 9 ($=3 \times 3$) times as great; and the resistance, in the one case, will be to that in the other $::1^2:3^2$:—that is, as the square of velocity.

70. This reasoning holds, only when the moving body remains immersed to the same depth. But, sometimes—as in the case of swift boats on canals, steam vessels, &c.—the elevation of the body, out of the water, and its ascent up the inclined plane, formed by the wave at the bow, more than compensates for the increased velocity; so that, as is found in practice, a greater may often be maintained, with a smaller consumption of force, than a less speed. The velocity, at which the minimum power is required, depends on a variety of circumstances—the breadth of the canal, the size and build of the boat, &c.

71. Since the resistance, opposed to a body moving in a fluid, depends on its surface, and on the density of the fluid; it varies as these, conjointly. But, as far as the surface is concerned, it varies as the square of the sine of the angle, made by the surface with the direction of motion.—For, let AB, fig. 150, be the section of a given surface. Its reaction is represented [mech. 76] by DE, a line perpendicular to it:—but FIG. 150.
DE is the sine of the angle BAD. Also, the quantity of water, displaced by the moving body, evidently varies as BD, which is, likewise, the sine of the angle BAD.—Hence, with a given surface, when both the reaction of the surface, and the quantity of water displaced by it, are variable, the resistance varies as the square of the sine (sine BAD \times sine BAD) of the angle, at which the plane is inclined to the direction of motion.



The result is the same, whether it is the plane, or the fluid, that moves.

72. Another source of resistance, to bodies moving in a fluid, arises from the partial vacuum which is produced, behind them.

The sooner, and the more easily this is filled up by the fluid, the greater the extent to which the resistance in front is counteracted. Experiment shows that, the bow and the stern of a ship being unchanged, the longer, within certain limits, its body is, the less the resistance.—This arises, from the velocity, and divergence, of the particles pushed away by the bow, being diminished, so that, when they arrive at the stern, they fall in more easily.

73. It is found that the resistance of a sphere, is to that of a plane, having a surface equal to the surface of a great circle of

the sphere::1090:2508. That the resistance of a cube, side foremost, is to that of the same cube, solid angle foremost ::877:1000. Colonel Beaufoy's experiments, which were made with great care, and at considerable expense, give the following resistances, at six feet below the surface—

	1 nautical mile per hour. lbs.	2 n. miles per hour. lbs.
A triangle, whose base was equal to 1 sq. foot	= 1.12	64.61
Ditto, base foremost	= 2.86	194.37
A cube of 1 foot	= 3.05	202.30
An iron plane, 1 foot square	= 3.25	203.79
A round iron plane, surface equal to 1 sq. foot	= 3.13	205.13
A cylinder, whose base was 1 square foot, its length 1 foot	= 2.84	190.78
Same cylinder, with semiglobe on stern	= 2.34	167.97
Same cylinder, with semiglobe on head end	= 0.93	55.34
Same cylinder, with semiglobe on each end	= 0.75	46.29
A globe, whose great circle was equal to 1 square foot	= 0.88	64.87

12 feet per second.
lbs.

A cube of 12 inches, with a triangle 3 feet long at the head end, and a triangle 4 feet 6 inches at the stern	= 33.11
With triangles, each 3 feet long	= 33.03
With triangle at base, 4 feet 6 inches long, hemicylinder at head	= 37.21
With triangle 3 feet long at base, hemicylinder at head	= 37.34
With triangle 3 feet long at head end, plane base at stern	= 48.62
The same, with hemicylinder at stern	= 42.81
The same, with hemicylinder at both ends	= 47.61

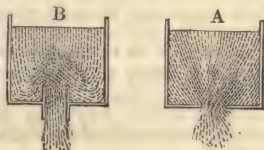
74. He found that the nearer the given body was to the surface, the more retardation was caused, in dividing the fluid.—When bodies are not fully immersed, resistance will be diminished, by the absence of friction at the upper surface.

75. SPOUTING FLUIDS.—If a fluid passes along a tube of different diameters, the velocity with which it flows, through the various portions, is inversely as their section. For the same quantity must pass through each part, in the same time; the smaller the part, therefore, the greater the rapidity, by means of which, it must compensate for that smallness.

76. If there is an orifice, at the base of a vessel A, fig. 151, which is small, compared with the size of the base; the section of the fluid becomes less, after it leaves

FIG. 151.

the vessel. This arises from the particles crossing, and interfering with each other, on account of the direction they take, in flowing from all parts to supply the vacuum over the aperture. The narrow part is called the *vena*



contracta;* and Sir I. Newton found it to be, at a distance from the vessel, equal to the diameter of the aperture; and to bear to the aperture the ratio of 21:25:—hence the areas are as $21^2:25^2$; or $1:\sqrt{2}$, nearly.

77. The vena contracta is produced, also, when a tube is used to convey the fluid from the aperture: but Venturi remarked, that more water flowed from the bottom of a vessel B, fig. 151, having a pipe the length of which is twice the diameter of the aperture, than from the vessel A, having an aperture without a pipe. And it is found that, while a cylindrical pipe, the length of which is four times its diameter, discharges a quantity represented by 84, a mere opening, will discharge one represented by only 64.—The diminution arises from the middle of the jet, alone, having all the velocity due to the height of the fluid above the aperture. If the pipe projects within the vessel, it lessens, rather than increases, the effect.

78. The velocity, at the vena contracta, is that which a body would acquire, in falling through a distance equal to the height of the fluid above the orifice—since it is derived from the action of gravity on the descending fluid. And the velocity, at the orifice, is what would be acquired by a body falling through half the height of the fluid, above the orifice.†

79. When a cylindrical, or prismatic vessel, empties itself through an orifice at the bottom, the velocity of the fluid, at the orifice, is uniformly retarded. For its velocity varies [78, note] as the square roots of the height of the columns above it—that is, as the square roots of the spaces, still to be described by the upper stratum of fluid, in its descent:—which is exactly the way in which [mech. 62] the velocity of a body, projected upwards perpendicularly from the earth's surface, varies. And, as in the latter case, the retardation is uniform, so also must it be in the former.

80. It is evident that, if different quantities of fluid are placed in such a vessel, they will vary as the squares of the times they will require, to flow out.

81. When the vessel is cylindrical, or prismatic, the velocity with which the surface descends, is uniformly retarded.—For

* Contracted vein. *Lat.*

† For, as we have seen [75], the velocity at different parts of the same current, is inversely as the section; hence the velocity at the orifice, is to the velocity at the vena contracta, as $1:\sqrt{2}$. But the spaces, through which the bodies fall, are as the squares of the last acquired velocities [mech. 50]. Therefore the spaces through which the fluid should fall to acquire the velocities at the orifice and vena contracta, respectively, are as $1^2:\sqrt{2}^2$, or as $1:2$. But the velocity, at the vena contracta, is that which would be acquired by a body, falling through a distance equal to the height of the fluid above the orifice.—Hence, the velocity, at the orifice, is that which would be acquired by a body falling through half that distance.—It varies, therefore, as the square root of half the height of the fluid above: or, which is the same thing, as the height itself.

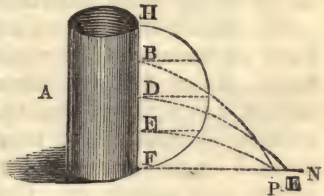
the velocity of the upper stratum is to the velocity of the stratum at the orifice, as the surface of the latter is to the surface of the former [75]. But the ratio between the two surfaces being constant, the ratio between the two velocities, also, will be constant; and one of them will vary as the other.—Hence, as the velocity at the orifice is uniformly retarded, the velocity of the descending surface will be uniformly retarded also.

82. If the vessel is a *parabolic conoid*,* the surface of the fluid will descend with a uniform velocity.—For, from the nature of that solid, the horizontal strata are proportional to the square root of the corresponding altitude; so that, according as the velocity is great or small, the quantity of fluid to be carried off, through the aperture, will be great, or small, also. A conoid 24 feet high, having an extreme diameter = 13.28 feet, and an aperture at the bottom = 0.424 inches, would form a clepsydra [mech. 258], the surface of the fluid in which, would descend uniformly: and it might be used to measure time, during 24 hours.

83. If a cylindrical, or prismatic vessel, is kept constantly full; twice as much as it can hold, at once, will run out, during the time in which, it would have emptied itself.—For, when it is allowed to empty itself, the velocity with which the upper stratum of fluid descends, is constantly retarded; until at last it = 0. But if the vessel is kept constantly full, the velocity with which the upper stratum descends, never decreases. Therefore [mech. 52], the effect in the latter, is twice what it would be in the former case.

84. To find the distance through which the fluid will spout from an orifice in the vessel A, fig. 152.—Let HF, its height, be bisected at D. With D as centre, and DH as radius, draw a semicircle. Take, on the line FN, FP = twice the ordinate drawn from the points B, or E—equidistant from D—to the semicircle. FP will be the distance to which the fluid would spout, in vacuo—the vessel being kept full—from B, or E. Take FE = twice the ordinate from the point D. It would spout from D, to E. In the same way twice the ordinate, from any point to the semicircle, will represent the distance, on the line FE, to which the fluid would spout, from that point. This may be proved by experiment.

FIG. 152.



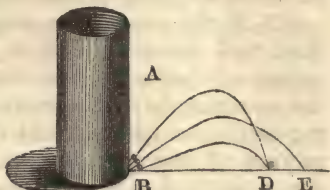
85. Thus it is found that the fluid will spout to the greatest distance, from the centre point D; and to the same distance from any two points, equally distant from D. The fluid will follow

* A solid, generated by the revolution of a parabola, about its axis.

the laws of projectiles [mech. 139], and, in every case, describe a parabola.

86. If fluid in a vessel A, fig. 153, spouts from a tube at B, making some angle with the horizon; it will be thrown to the greatest distance E, when that angle is 45° ; and to the same distance D, from two tubes, when the angles they make with the horizon are equally above and below 45° . Thus, when, for example, they are 47° and 43° . This, also, may be proved by experiment.

FIG. 153.



87. MOTION OF FLUIDS IN PIPES, &c.—If a pipe, attached to an aperture in the bottom of a vessel [76], is contracted in the middle, so as to form two frusta of cones, when the smaller extremities are united at the vena contracta, the discharge of fluid will remain unchanged: and the effect produced by them is greatest when, the diameter of the contracted part being five-eighths of the diameter of the aperture, it is placed, at a distance from the vessel, but little more than half the diameter of the aperture—the outer frustum being five times as long as that which is next the vessel. If the outer frustum is removed, the discharge will be diminished in the ratio of 4:3.

88. Causing a fluid to pass through pipes renders the speed, with which it moves, much less than it would, otherwise, be: and the diminution is increased, by making the velocity of the fluid greater, by roughening the interior of the pipe, &c. It is found that every length of tube, amounting to fifty times its diameter, produces a waste of power equal to that which produced the general impulsion.

89. Enlargements and contractions of the pipes diminish the force of impulsion, by requiring a change in the velocity of the fluid. Sharp flexures lessen the speed, to a very considerable extent.—It is found that the square of the velocity is diminished to an amount, expressed by the product obtained by multiplying that square, into the square of the sine of the angle of deflection, and dividing the result by the constant number 270. While an angle of 30° would cause a loss of the 2,160th part of the force, a right angle would cause the loss to become the 540th part.

FIG. 154.



90. The air, which spontaneously separates from water, collects in the higher portions of the pipes, and must be allowed to escape by valves, or other contrivances.

The *ventilator*, or *windpipe*, fig. 154, is often used for this purpose:—the air, which collects in the upper portion of the curved pipe, being occasionally let off, by the cock B. Valves, made self-acting by floats, are sometimes used instead of B.

91. When the pressure within a pipe is great, it will, sometimes, be burst, by suddenly closing a cock—and thus stopping the motion [31]. This is prevented, by the use of a loaded safety-valve, similar to what is attached to the steam boiler, and which will be explained hereafter.

92. We may ascertain the quantity of a fluid which passes through a channel, &c., by multiplying its transverse section by its velocity. The latter may be known from the height, down which it has fallen—allowance being made for the resistance, arising from friction, &c.: or it may be determined, practically, by marking, with a stop watch, the mean time required, by slices of turnip, &c.—which have nearly the same specific gravity as the fluid—to pass through a known distance.

93. Bernoulli found that, if a small vertical pipe is attached to one that is conical and is either vertical, or horizontal, while water passes from the smaller to the larger end of the latter, fluid will be drawn up, in opposition to gravity, from a vessel into which the former descends.

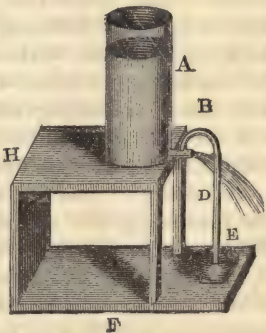
94. This is a consequence of what I have already noticed [31]: and may be illustrated by the apparatus, fig. 155. A cylinder, one inch wide, and three inches long, which is fixed in the lower part of the vessel A, has inserted into its upper side, at a short distance from A, a small arched tube BD, descending into the vessel E: and the whole rests on a stand HF.—

 If the stream is projected, from A, with a velocity of nine feet per second, the water will rise in D, to the height of two feet. Or, if D does not exceed two feet, the column within it will mix with body of the current issuing from A; and the vessel E will be drained.

FIG. 155.

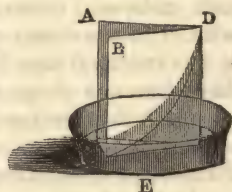
If a small opening is made in a conducting pipe, air will be drawn in, and the flow of water will not be continuous.

95. This principle causes the centre of a stream to be higher than its sides—the water being drawn from the latter, by the fluid which is in rapid motion. Venturi, availing himself of it, used the lateral draft of a mill-race, near Modena, to drain a marsh, situated at a much lower level. And we find it applied even in the animal body:—for two currents of blood, entering a large trunk, are, sometimes, made to exhaust a smaller vessel, lying between them.

96. **CAPILLARY ATTRACTION.**—The attraction of cohesion gives to fluids a tendency to assume the spherical form: and causes several drops to unite into one—as may be exemplified, by mercury. This tendency is applied to a practical purpose, in the manufacture of small shot—which, it is evident, could be formed but very imperfectly, and not, without great expenditure of time, and apparatus, by casting the metal, in moulds. The process employed is extremely simple.—Lead is melted, and allowed to drop, in the fluid state, from the top of a high tower, through a perforated metallic plate. The attraction of cohesion causes the drops to become perfectly round; and their sphericity is permanent, since they are cooled, during their descent, and are received below, in water—which prevents their being injured by the fall. The different sizes are separated, by allowing the shot to roll down a metallic inclined plane, containing apertures, which become larger, as their distance from the top increases:—the grains, that are badly formed, run off the plane, at each side.

97. An attraction is found to exist, between solids and fluids.—This is termed *capillary*,* because it is most strikingly illustrated by very small tubes. It has been said [32] that the surface of a fluid is horizontal:—This happens, however, only when no disturbing influence is exerted. If a solid is plunged into a fluid, the particles, next to it, will not remain at their former level.—Thus, when two plates of glass, A and B, fig. 156, forming a very small angle ADB, are placed, vertically, in the vessel E, containing water—tinted, if possible, with some colouring substance, the fluid will ascend between them; and its height will increase, as they approach each other more nearly. The curve, formed within the plates, by the surface of the fluid, is an *hyperbola* [mech. 139; note]. The increased height of the fluid, as it approaches D, is caused by the influence of one plate reaching within that of the other:—the nearer the plates are, the greater the vertical space over which that quantity of fluid, which the attraction of the plates can sustain in opposition to gravity, will be diffused—on account of its thickness having become less. A very small tube may be supposed to consist of an infinite number of plates, ranged round a central point, acting in every direction, and having a combined effect.

FIG. 156.



98. Water has been found to ascend in capillary tubes, to the height of 21 inches.—It is curious that, when electrified, they will discharge water through them with great rapidity; though, otherwise, from the smallness of their bore, they would be incapable of transmitting it.

* *Capillus*, a hair. *Lat.*

99. Mutual attraction does not exist between all solids and fluids: on the contrary, some of them repel each other—thus, glass, and mercury. When this occurs, a *depression* will be found in the surface of the fluid, which has the same outline, as the *elevation* formed by attraction:—but the curve, will be turned in exactly the opposite direction.

100. The elevation, or depression, of the same fluid, in a tube, is inversely as the internal diameter of the tube; and has nothing to do with its thickness:—which shows that only the innermost film produces any effect. Hence, a coating of moisture destroys the properties of a glass tube, and causes mercury to rise within it.—The coating acts as a tube, and removes the mercury beyond the repulsion of the glass. If a tube have a diameter less than the twentieth of an inch, it is generally considered capillary. If its diameter is the fiftieth of an inch, water will rise in it to the height of one inch.

101. If two plates, held parallel, are partially immersed in a fluid, and brought towards each other, as soon as the similarly curved surfaces of the fluid come into contact, the plates will rush together.

102. When two hollow glass balls are made to float in water, so near each other that those portions of the surface of the fluid, affected by them, will be in contact, they will unite; for the water, which is raised between them, by attraction, will, in sinking down under the influence of gravity, draw them together. Also, if they are both incapable of being moistened—as two balls of wax—when they are sufficiently near, they will unite; for, a hollow being formed, between them, the pressure of the water on the surfaces, which are farthest apart, will not be counteracted, by an equal pressure against those which are nearest. If one is capable, and the other incapable of being moistened, in similar circumstances, they will separate: for, since the one attracts fluid, which repels the other—the water being raised by one, and depressed by the other, they cannot remain within a certain distance of each other.

103. If a drop of water is placed in the wider end of a small conical glass tube, capillary attraction will cause it to move rapidly towards the smaller extremity. The drop, when in the tube, is bounded at each end by a concave surface; but that which is at the smaller end, being the most curved, exerts the greatest attraction for the sides of the tube, the attraction being according to Laplace, inversely, as the radius of the curve terminating the column:—this excess of attraction causes the drop to move in that direction.

104. Repulsion sometimes exists, between fluids. Hence, air and water cannot pass each other in a very small tube.—The attraction between the glass and the fluid will prevent the latter from being driven out by the air.

105. The height to which fluid rises in a capillary tube is not, as we might at first suppose, increased by diminishing the density of the fluid; for alcohol, which is lighter than water, will not rise so high, by capillary attraction. Indeed the height does not seem to have any connexion with their specific gravity:—for oil of turpentine, which is about one-seventh lighter than water, rises only one-fourth as high; and an aqueous solution of ammonia, which is one-tenth lighter than water, rises one-fifth higher. Hot and cold water rise to the same height.

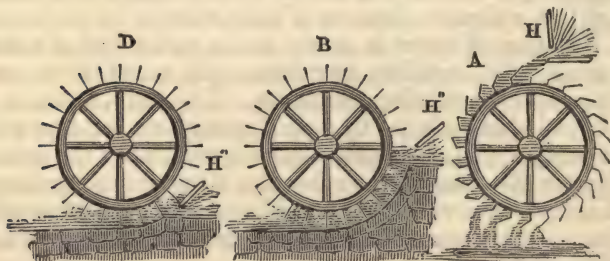
106. The insinuation of fluids between solids, at small distances from each other, is always referable to capillary attraction. It causes oil to rise in the wick of lamps, water to be absorbed by bibulous paper, &c. Some substances, such as linen, &c., are easily wetted, on account of their attraction for water being considerable in amount. And a vessel of water may be emptied, by hanging over its edge, a towel which dips into the fluid. Others are moistened with more or less difficulty, for the contrary reason:—hence, silk, or wool, does not answer so well as cotton, or linen, to dry the hands, after they have been washed.

107. Some have supposed that capillary attraction causes the ascent of sap; but the effect is far greater than can be attributed to this cause.—For, it has been found, that, on removing the top of a tree, and inserting a glass tube into the part which remained, the sap continued to rise through many feet of the tube.

108. HYDRAULICS—VERTICAL WATER WHEELS.—Water is made to drive machinery, either by its weight simply, or by its momentum. The effect is obtained, most generally, by “water wheels,” which are of three kinds—the overshot, the breast, and the undershot wheel.

109. *The overshot wheel*, A, fig. 157, receives water from

FIG. 157.



the sluice H, in buckets: and the pressure, at two opposite sides, being, thus, rendered very unequal, a rotary motion is produced.—Very little effect is due to the velocity of the water. The form of this wheel should be such, that the buckets will

receive the fluid, as soon, and retain it just as long, as it will be effective:—otherwise it will be only a source of pressure upon the axle.

110. *The breast wheel* is represented by B. fig. 157: its float-boards are prolongations of the radii; and the water is retained between them, by means of the masonry behind. If this is too close to the wheel, friction will be produced; if too far from it, a considerable quantity of the fluid will escape:—either would lessen the force, obtained. The fluid acts on the wheel by its weight: but the effect is increased by the velocity, which it has previously acquired.

111. *The undershot wheel*, D, fig. 157, differs from the breast wheel, by its float-boards being sometimes so arranged as to form a small angle with the radii, produced: and, by their being, in some instances, curved. The water acts upon this wheel, by its momentum. Undershot wheels are, often, fixed between boats, on rapid rivers.—There is a great number of them in a row, across the Rhine, at Mayence.

112. From the experiments of Smeaton, it appears that the dimensions, quantity of water, and height of the fall, being the same, an overshot will produce double the effect of an undershot wheel.—The breast wheel, and all others which do not allow the water to descend unless they, also, move, are to be considered as overshot; and they possess a power, proportioned to the height, through which the water descends. The effect of a breast wheel should be the same as that of an undershot wheel, whose *head of water** is equal to the difference of level between the surface of the stream, and the part where it strikes the wheel, added to the effect of an overshot wheel, whose height is equal to the distance from the striking point to the *tail water*.† But, as the fluid does not strike at right angles, and from other causes, the breast wheel is found, in practice—all things else being alike—to consume twice the quantity of water, required by an overshot wheel, to do the same work.

113. If a water wheel had no resistance to overcome, it would move with the velocity of the stream by which it is driven; if loaded with a resistance equal to the power of the stream, it would not move at all:—its effective velocity is between these extremes. It is found that an overshot wheel produces a maximum result, when its velocity is three feet per second.

The length, and capacity of the buckets may be easily found,

* The “head of water” is the distance between the aperture of the sluice and the place where the fluid strikes the wheel.

† The “tail water” is that which is discharged from the bottom of the wheel, after having produced its effect.

when the quantity of water, supplied by the stream [92], is known. If the stream delivers, for instance, 18 cubic feet per second, and the buckets are to be 6 inches apart, there will be six buckets in three feet; each, therefore, if the motion is 3 feet per second, must contain 3 cubic feet. The quantity of water, supplied by the stream, may be determined, very conveniently, by "extracting the square root of the depth, in feet, from the surface of the water to the centre of the orifice of discharge and multiplying the result by 5.4:—the product will be the velocity, in feet, per second; and this multiplied by the area of the orifice, in feet, will give the number of cubic feet which flow through, in a second."

114. An undershot wheel produces its maximum effect, when its circumference moves with, between one-half, and one-third of the velocity of the stream.

115. The part of the wheel, from which the power is obtained, is a very important consideration.—To take it from either the axis, or circumference, would be incorrect. There is only one point of a striking or revolving body, where its action may be supposed to be concentrated, and at which, if a force, sufficient to cause the body to stop, is applied, it will, without any strain, at once assume a state of rest. In striking bodies, it is called the *centre of percussion*: and when they revolve round a fixed point, it coincides with the *centre of oscillation* [mech. 264]: but when they move parallel to themselves, with the *centre of gravity* [mech. 94].—It is well known that a stick of uniform density and thickness, will give the most efficient stroke, at a point two-thirds distant from the extremity about which it revolves. If it increases in thickness towards the end which is farthest from the centre of motion, its centre of percussion will approach nearer to that extremity. The same laws apply to all wheels, from which power is taken. As the rim of the water wheel is comparatively, very heavy—particularly that of the overshot, which contains water in the buckets upon one side—the point at which the greatest effect will be produced, is very near to it. In practice, it is usual to consider its distance from the rim, as equal to one-fourth of the radius. Placing cogs on one of the rings of the water wheel, or using a driving wheel, equal to it in size, is very injudicious.

116. If the power is taken from a point too near the centre of motion, the outside of the wheel will have a tendency to move with greater velocity, than its central part—which may cause the shaft, or axle, to be broken.

117. To prevent unequal strain, the power should be taken, also, from a point, opposite to where the water produces its greatest effect.

118. The power of an overshot wheel is to the effect produced :: 3 : 2. But the power of an undershot wheel is to its effect :: 3 : 1 :—when, however, curved floats are used, the effect is two-thirds, or even three-fourths of the power.

To ascertain the “horse power” of any wheel, we have only to divide the number of pounds, of *actual effect*, per minute, by 33,000—this being, as we shall find, what is considered to be a horse power, and is taken as the standard of comparison.

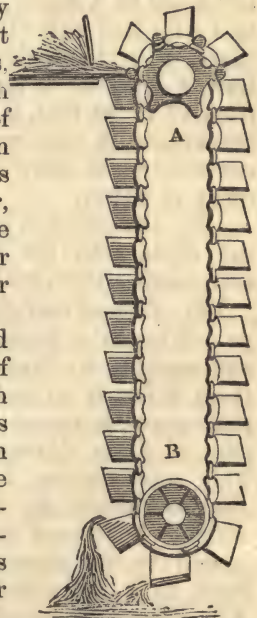
EXAMPLE.—A stream supplies 45 cubic feet of water per second, to an overshot wheel, moving at the rate of 3 feet per second. What is its power ?

The effect being equal to two-thirds of the power, the supply may be considered as 30 cubic feet per second. And, as a cubic foot of water weighs about 63 lbs. The effect is $30 \times 63 = 1890$ lbs., falling 3 feet per second—and therefore, capable of raising 1,890 lbs. 3 feet per second: or $1,890 \times 3 = 5,670$ lbs. 1 foot per second; and $5,670 \times 60 = 340,200$ lbs. 1 foot per second.

But $340,200 \div 33,000 = 10\frac{1}{2}$, horse power, nearly—which is that of the given wheel.

119. It is important that the “tail water” should escape with as much facility as possible, otherwise the resistance, offered by it to the motion of the wheel, will consume some of the power. The principle, already mentioned [93, &c.], is used to effect this object. Two drains, or tunnels, are made through the masonry, at each side of the wheel, so as to permit some of the water, from above, to flow down in front of the wheel.—The current, thus produced, will [95] carry off the water, which is injurious; and no inconvenience occurs, as *tailing* happens, only when water is plenty. The drains may be closed, or regulated, by sluices.

FIG. 158.

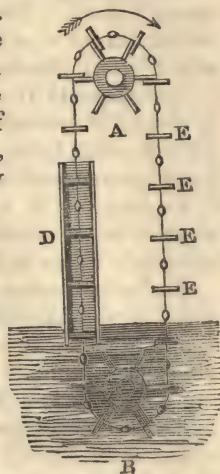


120. *Chain Wheels* are sometimes used when the fall is high. They consist of two wheels, A and B, fig. 158, over which passes a chain of buckets. The power is supposed, in the figure, to be taken from A, and B is intended as a guide: but the arrangement may be reversed, when necessary. This machine is found to be extremely inefficient, on account of the loss of power by friction, &c.; and the wear and tear, also, is very considerable.

121. *The Chain-pump* is somewhat similar, in construction, to the chain wheel:—it is used in ships, &c., and consists of

two wheels A and B, fig. 159, and a series of plates, connected together by iron work. B guides: but A both moves and guides, the plates, which pass up, on one side, through a barrel D, that fits them with tolerable accuracy. This pump has the advantage of not being easily choked with sand, &c., which would destroy one of the ordinary construction.

FIG. 159.

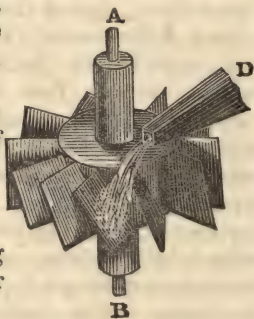


122. **HORIZONTAL WATER WHEELS, OR TURBINES.** The wheels which I have described, are vertical, and their axles horizontal: but what are now generally designated “turbines” are horizontal, having vertical axles.

123. With horizontal wheels, the force is derived from impact, pressure, or reaction—but never from the weight of the water.

124. *Impact Wheels* are very simple, but not very efficient.—Rectangular floats, fig. 160, making with the horizon an angle of between 50° , and 70° , are fixed to a wheel, which turns on the axis AB; and water is thrown upon them, nearly at right angles, by the trough D. Such a machine is used, when the fall is from 10 to 20 feet, if a great number of revolutions is required, and simplicity of construction is more important, than economy of power.

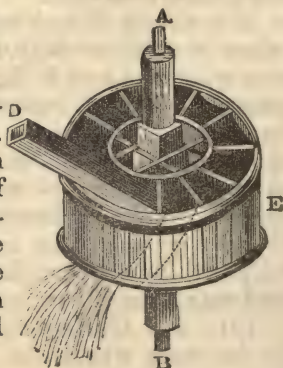
FIG. 160.



125. The effect is increased by forming the floats into the shape of spoons, or surrounding them with a rim.

FIG. 161.

126. *Impact and Reaction Wheels, &c.*—When the floats are lengthened, and curved—so that the water leaves them in nearly an horizontal direction, their power is augmented, by the quantity of force derived from reaction. This construction is exemplified in *Bordas turbine*, fig. 161, the floats of which, are formed, in the way represented by the dotted lines, and are fixed to a rim attached to the axle AB: the whole revolves freely, in an external case E, and water is supplied by the trough D.

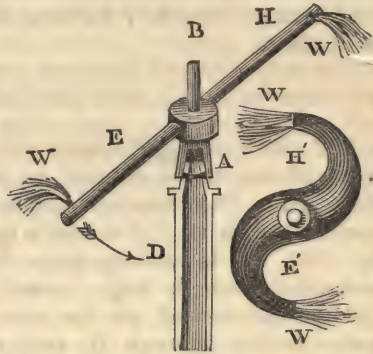


127. *Pressure Wheels*.—If the water acts, without impact, by pressure only, the machine is termed a “pressure wheel.”

128. *Reaction Wheels*.—If water flows from D, fig. 162, into the horizontal tube EH, ca-

FIG. 162.

pable of turning round, at A, as long as EH is closed on all sides, there will be no motion. But if an aperture is formed at one side of E, and another, at the opposite side of H, the water will escape: and, the pressure, on the portions exactly opposite to these apertures being now uncounteracted, EH will revolve.—This rotary motion may be communicated to machinery, by means of a



spindle B. The *theoretical* effect will be obtained, by multiplying together the area of the apertures, the pressure per square inch—which depends on the height of the column above the centres of the orifices—and the velocity of the arms at the apertures. But, the result is greatly diminished by the fulcrum, against which the water acts, being movable—a portion of the force being expended, in producing the velocity with which the escaping fluid moves, in the opposite direction. The force obtained is evidently proportional to the water used:—for the larger the openings, and the greater the pressure, the more water will escape.

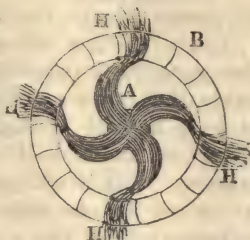
129. In the older forms of this apparatus, termed *Barker's Mill*, there was a great waste of power, on account of the water being let in *above* through a vertical tube, occupying the same position as B, fig. 162, and of the same height as the column of fluid, whence the pressure was derived;—great force was necessarily expended, in causing this column to revolve along with the horizontal arms. But in the form represented, the water is let in *underneath*, and the apparatus revolves water-tight, at A, by means of a conical joint—the front of which, in the figure, is supposed to be removed, that the interior may be visible. This is but little affected by wear, since the weight above it is, almost entirely, supported, by the upward pressure of the water acting immediately under B.

130. A greater effect is obtained from the fluid, if the arms are curved, as represented by H'E', fig. 163:—since it *gradually* imparts motion, by pressure against the curved sides: and has, but little velocity, when it leaves the apertures.

131. The force, however, which still remains, may be employed

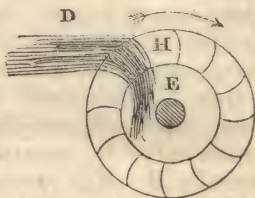
to drive a second wheel B, fig. 163, which, it is evident revolves, in a direction opposite to that of the arms; but the effects may be combined, by reversing the motion of either—with some of the contrivances, which I have noticed, in mechanics.

FIG. 163.



132. *Tangential Turbines* are those, in which the tangential force of the water is used to produce the effect. Their mode of action may be understood, from "*Poncelet's turbine*," fig. 164. It is nothing more than an undershot wheel, with curved floats [111], and turned on its side. The water enters through D, and, running along the curved channels, is discharged into the interior E. The tangential force, which it has, on entering, tends to carry it faster than the parts of the wheel, nearer the centre; and, having a higher velocity than these parts, it increases the rapidity with which they revolve.

FIG. 164.



133. Vertical water wheels can scarcely be used, when the fall exceeds 60 feet; turbines may be employed when it is so much as 500 feet. But the higher the fall, the less in proportion, the effect of the turbine; and the resistance increases, as the square of the velocity [88, &c.] When the fall is between 20 and 40 feet, vertical wheels are more effective than turbines: when it is between 10 and 20, they are on a par: when it is lower than 10, the turbine has the advantage. Turbines are greatly affected by a change in the supply of water. The better kinds of turbine require considerable skill, in their construction; but, on the whole, their expense is about equal to that of the vertical wheel—circumstances being the same.

134. *Water-pressure Engines* will be understood, when I shall have treated of the steam engine; since these two kinds of machine are very like, in construction—the chief difference being in the moving power.

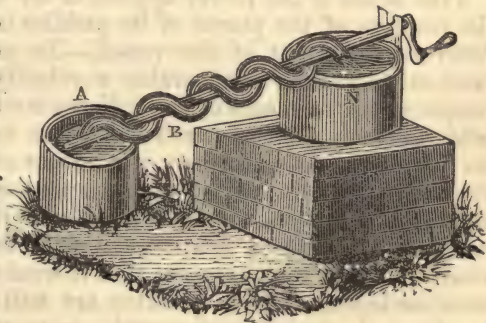
135. **PADDLE WHEELS OF STEAM VESSELS.**—A great number of contrivances have been, at various times, invented for the propulsion of vessels by steam, &c.: among others, apparatus, resembling the fins of fishes—the feet of ducks, &c.—water drawn in, at the bow, and forced out, at the stern, &c. But those which have been found most successful, are the "paddle wheel," and the "screw."—The former is very similar in shape,

and action to an undershot water wheel:—but there is this difference, that with the one, the wheel drives the machinery, while with the other, the machinery drives the wheel. The great imperfection of paddles is, that, when they enter, and when they leave the water, power is wasted—in the former case, by *depressing*, and, in the latter, by *lifting* the fluid. This is called the *back-water*; and many methods have been suggested to remove, or, at least, to lessen the evil arising from it. The chief of these, have had for their object, to make the paddles *feather*—that is, to make them enter and leave the water perpendicularly—which is effected by the rower, when he “feathers” his oar. But complication of construction, or error in principle has caused many of these contrivances to be abandoned; and the simplest form of paddle wheel, is that which is still, almost universally, adopted.

136. The depression, and lifting of the water are found to produce another serious inconvenience—a destructive and unpleasant vibration of the machinery and vessel, which is often much increased, by the ebullition of the water in the boiler. What is due to the former cause, is diminished, by breaking the paddles, longitudinally, into small portions, arranged parallel with each other—but so as to lie in a curve. The effect is, then, neither so injurious, nor so disagreeable—since it is divided into smaller portions, and is rendered more continuous.

137. THE SCREW OF ARCHIMEDES, is said to have been invented, by that celebrated philosopher, about 200 years, before Christ, for the purpose of draining land, in Egypt: others, however, ascribe it to the Egyptians. It consists of a hollow spiral

FIG. 165.



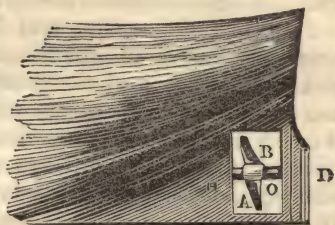
tube, B, fig. 165, wrapped round an axis, along with which it is turned by means of a handle.—Sometimes it is moved, by a small paddle wheel, attached to its lower extremity. As each part of the screw, during its revolution, changes from a lower to a higher position, the fluid within it falls backwards, but, at the same time, is lifted by the under surface of the interior, so that it gradually ascends from A, until, at length, it flows into N.

138. A machine, somewhat analogous, consists of a wheel, the spokes of which are hollow, and curved.—Water is taken

in at the circumference, and delivered at the centre: and the machine may be moved by float-boards, fixed on the side of its rim, &c.

139. SCREW PADDLES.—The various inconveniences attending the use of paddle wheels, have caused them to be more, or less, superseded, by the “screw paddle,” which, from a distant resemblance to an apparatus, already described [137], has been termed, by some, the “Archimedean Screw.” We find, by the Transactions of the American Philosophical Society, that it was used at New York, by Bushnell, of Connecticut, so early as the year 1776—being intended to propel a submarine boat, contrived for the purpose of fixing to the bottoms of ships, an explosive preparation, by which they were to be blown up. It

FIG. 166.



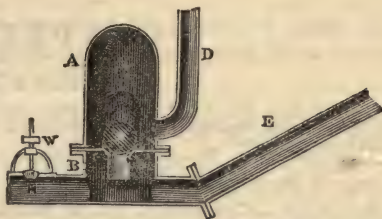
consists of a variable number of paddles B, A, &c., fig. 166, constituting portions of a plane wrapped round an axis, in such a manner as to be attached by its edge, and form parts of a screw, having a thin but very deep thread. The axis to which the paddles are fixed, passes through a water-tight aperture, into the vessel; and a rapid motion is communicated to it, by means of a steam engine—generally in conjunction with a powerful wheel and pinion, which increase the velocity of rotation. The screw is most usually fixed in an aperture in the dead wood, exactly in front of the rudder; and is sometimes so arranged, as that it may be lifted up, when not in use.

140. Much of the power applied to the screw is wasted, since the reaction of the planes of its paddles is in a direction very different from that of the vessel.—To produce any effect, it must move with so considerable a velocity, that obtaining the proper speed, by means of the ordinary steam engine, is attended with difficulty and inconvenience. The screw causes little, or no disturbance in the water; it does not affect the symmetry of the vessel: and it is always submerged—which is not the case with paddle wheels, one or the other of them being, in rough weather, often raised completely out of the fluid: and it is, in many respects, so convenient that it would be fortunate if the disadvantages, which in practice, are still found, more or less, to attend its use, were removed—so as to cause its universal adoption.

141. THE HYDRAULIC RAM.—I have said [91] that, when the flow of water in pipes is suddenly checked, a considerable force is generated. This property of fluids, which is sometimes attended with inconvenient results, has been usefully applied, in

what is called the “hydraulic ram.”—A valve H, fig. 167, allows the water to escape, and thus, a current is produced, in the inclined pipe E—in which, the fluid acquires, by this means, a momentum sufficiently great to close H. The motion being thus suddenly

FIG. 167.



checked, a pressure is generated, sufficient to lift the valve within the vessel A, and ultimately to force the water up through the pipe D.—The valve in A is, most conveniently, made in the form of a ball, which is prevented from rising too high, by a metallic bridle. The stoppage of the water diminishes its momentum, and it becomes incapable of any longer supporting the valve H—which therefore falls, and allows the fluid to escape : and the water descending through E, again acquires a momentum which closes H, and forces more of it into A. Thus the action is continued as long as the proper supply is maintained.

142. A very small fall, through E, will raise a column of considerable elevation in D:—but a large quantity of water escapes, at H. If the pipe E is not sufficiently long, water will be thrown back into the reservoir, instead of into A. The stream should not be variable, since the weight W must be adjusted to it.

143. The air in the upper part of vessel A, is gradually taken up by the fluid, and carried away ; but a fresh quantity is admitted by a valve B—above which a small vacuum is formed at each stroke.

CHAPTER V.

PNEUMATICS.

Objects of the Science, 1.—Properties of the Air, 2.—The Diving Bell, 8.—The Condenser, 10.—The Air Gun, &c., 14.—The Air Pump, 19.—Pressure of the Air, 28.—The Barometer, 30.—Pumps, 44.—Syphons, 53.—Sound, 56.—Conduction, &c., of Sound, 57.—Musical Sounds, 69.—The Gamut, 70.—Sympathy, 77.—Temperament, 83.—Tuning of Pipes, Strings, &c., 88.—Reflection of Sound, 95.—Concentration of Sound, 97.—Interference of Sound, 98.—Buildings for Public Speaking, 99.—Ventiloquism, 103.—The Wind, 104.—Anemometers, 107.

1. OBJECTS OF THE SCIENCE.—“Pneumatics”* treats of the mechanical properties of permanently elastic fluids, of which atmospheric air is considered to be the type, just as water is considered the type, or representative, of non-elastic fluids—so far as their mechanical properties are concerned. Although the mechanical properties of all non-elastic fluids, or all elastic fluids are the same, their chemical properties are, as we shall find, extremely different.

2. PROPERTIES OF THE AIR.—It is evident that air is a material substance, as it possesses those qualities which characterize matter.—It comes, even directly, under the cognizance of the senses; for, though like water, and many other fluids, it is invisible, when in small quantities, the case is very different when its mass is considerable—since it is then blue, and imparts that colour, to the objects which are seen through it.

3. The air is *impenetrable*; for, though we may diminish the space it occupies, we can no more annihilate it, than if it were one of the most unyielding substances.

4. It has *extension*:—since, not less than solid matter, it occupies some portion of space. And it possesses *figure*:—since, not being infinite, it must assume some definite shape.

5. It has *inertia*:—for it cannot be moved, when at rest, nor stopped when in motion, without the expenditure of force.—This truth is established by abundance of facts:—by the difficulty of moving bodies rapidly through the air: or of making large organ pipes speak: and by the force necessary to resist the wind, when in motion, &c.

6. It is *elastic*:—since it is capable of being either compressed, or rarified. The particles of elastic fluids do not seem to exercise any mutual attraction, but the contrary: for they are brought near each other, only by some force—as that of gravity, &c., and the smaller the distance which separates them, the greater the difficulty of overcoming their mutual repulsion.

* *Pneuma*, air. Gr.

7. The air, being like other material substances, affected by gravitation, has *weight*.

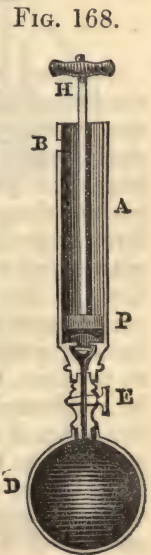
I shall now point out, how the most important of these properties are illustrated; and what apparatus is due to a knowledge of them.

8. **THE DIVING BELL.**—The impenetrability of air is exhibited by the “diving bell,” the principle of which, may be shown in a familiar way, by inverting a wine glass in water.—As the glass is immersed in the fluid, the bulk of the air in the upper part of it, is diminished; but, to whatever depth it may be sunk—and, consequently, to whatever pressure the air within it may be exposed, there will still be a portion of the vessel, into which the water will not enter.

9. The diving bell is a strong iron box, of any shape, open at the bottom, and having thick pieces of glass fixed, in various places, for the admission of light. The water which, as the bell descends, enters on account of the compression of the air within, is driven out by an additional quantity of air, forced in from above. To enable the workmen to remain in the bell, fresh air must be constantly pumped down: the vitiated air, being warmer, ascends, and escapes through an aperture in the upper part, into which the water cannot pass—on account of the pressure from within. The chief inconvenience experienced by persons descending in the diving bell, arises from the very condensed state of the air, which—particularly at first—causes a painful sensation in the ears, &c.: and they must not be stopped with cotton, &c., as it would be forced into the head. The workmen below communicate with those above, by signals.

10. **THE CONDENSER.**—The compressibility of the air may be proved by the condenser, fig. 168. It consists of a cylinder A, in which a piston P is moved air-tight, by the handle H. When P is forced down: the air under it being condensed, opens the valve in the lower part of A, and rushes into the vessel D. When P is drawn past the aperture B—forming a communication with the atmosphere—air rushes into A, and is, in the same way as before, driven down into D. This compression goes on, as long as the force, applied at H, is sufficient to open the valve D, in opposition to the force exerted against it, by the elasticity of the compressed air in the vessel: or until the latter bursts.

11. The pressure on the inner surface of D, is inversely, as the space occupied by the air within it. When it contains air of the same density as the external atmosphere, the pressure is said to be that of “one atmosphere.” When it contains



three times as much air as it would, if in communication with the atmosphere, the air within it occupies only one-third of its ordinary space; and its pressure is three times as great—or that of “three atmospheres,” &c.:—two, only, of these, however, tend to burst the vessel, one of them being, as we shall see, counteracted by the pressure of the air without.

12. We may prove that the air occupies a space Fig. 169. inversely proportioned to the force which compresses it, by means of the bent glass tube ABD, fig. 169, hermetically sealed at A. The dark part represents mercury, which, pressing on the air, in HA, diminishes its volume: and it will be found, on making the experiment, that doubling the pressure—taking that of the atmosphere into account [11]—H will diminish the space HA, to one-half; tripling the pressure, will diminish it to one-third—and so on. This law—announced by *Mariotte*—does not, however, hold in extreme cases.



13. Some gases become fluid under considerable pressure. The following require, to liquefy them—

Gases.	Pressure, in Atmospheres.
Nitrous oxide,	44
Carbonic acid,	36
Hydrochloric acid,	24
Sulphuretted hydrogen,	15
Ammonia,	5
Cyanogen,	3
Sulphurous acid,	2

14. THE AIR GUN, &c.—In this instrument, the elasticity of condensed air, is used for the propulsion of a ball. Air is condensed by the syringe, fig. 168, into a small, but strong spherical vessel, which is screwed to the gun. On drawing the trigger, a portion of the air, liberated by means of a valve, rushes along the barrel, and drives the ball before it, with a force dependent on the amount of condensation. The velocity with which a body is projected, being as the square root of the force, if the force of gunpowder is twice as great as that of compressed air, it generates four times as high a velocity. The force of gunpowder has been estimated at 1,000 atmospheres:—to produce, therefore, the same effect by means of air, it must be condensed, so as to occupy only the one-thousandth part of the space it naturally fills. But—the capacity of the receiver, attached to the air gun being large, compared with that of the barrel—the density of the air is but little altered by the discharge;—consequently, the ball is driven the whole length of the barrel, with nearly the same force—which is not the case,

when gunpowder is used. Hence, it is found that air, having the pressure of only ten atmospheres, will produce a very considerable effect.

15. *The Condensed Air Fountain*, fig. 170, consists of a strong copper vessel A, having a tube—which passes nearly to the bottom of it—inserted air-tight into its neck. A portion of the vessel being filled with water, a large quantity of air is to be forced into the space R, by the condenser [10]:—being lighter than the water, it will ascend through that fluid, and occupy the higher portion of the vessel. The stop-cock D, being closed, and the condenser removed, a variety of jets may be screwed on; and, when the cock is opened, the air, pressing on the surface of the water, will force it violently up through the pipe, and jets.*

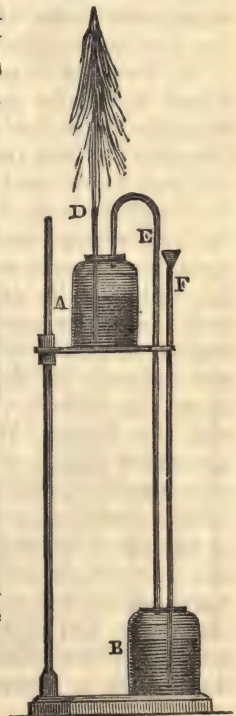
16. An air-vessel, acting upon this principle is attached to hydraulic machines, whenever an uninterrupted stream is to be obtained from an intermitting supply:—the size of the aperture, through which the constant stream is to issue, is made sufficiently small: and the pressure required, is supplied by condensation of the air. An air-vessel is used with the hydraulic ram [hyd. 141], &c.

17. *Heros' Fountain*, also, may be employed to illustrate the effect of condensed air.—In its simplest form, it consists of a bottle A, fig. 171, containing water, into which the long funnel F, dips: a small bent tube E, forms a communication between A, and another bottle B, which, likewise contains water—into which the tube D, having a small opening at its upper end, dips. When water is poured into F, it forces the air contained in the upper portion of B, through the tube E into A; and this air, pressing on the surface of the water, forces it in a jet, through D.

FIG. 170.

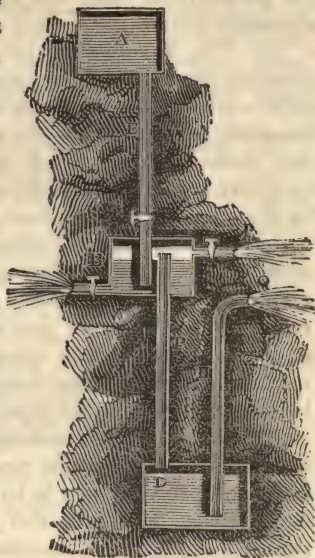


FIG. 171.



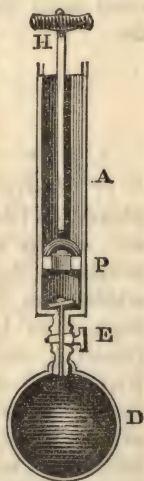
18. *The Hungarian Machine* is constructed on the same principle as Heros' fountain. It derives its name from having been used to drain a mine, at Chemnitz, in Hungary. —Three reservoirs, A, B, and D, fig. 172, are connected by pipes:—the reservoir D communicates, with the atmosphere, by means of H. When water is made to flow from A, into B, the air, with which the latter was previously filled, is driven down through the pipe P, and, pressing on the surface of the fluid in D, forces it to ascend in the pipe H, and flow out at Q. On opening the cock, for the purpose of removing the water from B, air and water rush out through it, with great violence: and the sudden expansion—for a reason to be explained hereafter—causes a cold sufficient to change the water into lumps of ice, which issue out with so great force as, sometimes, to perforate bodies like pistol bullets.

FIG. 172.



19. *THE AIR PUMP*, and a variety of experiments which it enables us to make, prove that the air expands, when the pressure is removed. It was invented by Otto Guericke, of Magdeburgh, about the year 1654; and was improved by Boyle. In its simplest form, it is an exhausting syringe A, fig. 173, which consists of a piston P, moving, air-tight in the cylinder A, by means of the handle H. When P is drawn up, the air under it expands, and its pressure is proportionally diminished, so that it is no longer able to counteract the pressure of the air in D—which, therefore, opens the valve in the lower part of A, and rushes into the latter. When P is pressed down, the air, which rushed out of D, being condensed, acquires sufficient elasticity to close the valve in the cylinder, and, after a while, to open that which is in the piston, so as to rush into the atmosphere. In this way the air is drawn out of D, until what remains within it is not elastic enough to raise the valve, in A.

FIG. 173.



20. Fig. 174 represents a more perfect form of a pump. It consists of two cylinders, or barrels—similar in construction to that which is represented fig. 173—worked by racks, and a

pinion which is moved backwards and forwards, by a handle. A ground brass, &c., plate, is fixed to a stand, which rests on pillars RR, and an aperture, in the centre of it, forms a communication between the receiver A, placed upon it, and the exhausting cylinders—by means of a small pipe, containing a stop-cock. The pillars O, and H, bind the various parts together, and the entire is securely attached to a strong frame NS. The valves in the cylinders, and pistons, consist, merely, of small circular apertures, over which are placed narrow strips of oiled silk, secured only at their extremities—that the air may pass freely, at each side of them, when they are raised by its elastic force.

The piston being drawn up, in one barrel, it is depressed, in the other: and the degree of exhaustion within A is indicated by the *barometer gauge* P, the cup of mercury, belonging to which, is seen at T.—I shall explain this gauge, presently.

21. Many improvements have been made, in the details of the air pump, since it was first invented. And a number of contrivances have been suggested for rendering the action of the valves more delicate—such as lifting them mechanically, and without any aid from the elasticity of the air beneath them, &c. Most probably, the best of the methods proposed is to relieve them of some pressure, by means of a subsidiary air pump.

FIG. 174.

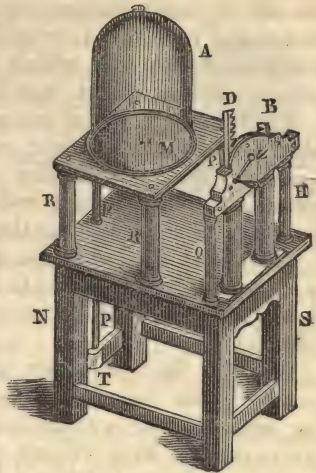
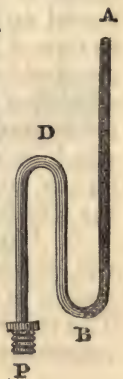


FIG. 175.

22. The *Syphon Gauge* is sometimes used, to indicate the exhaustion in the receiver. It consists of a bent glass tube, fig. 175, one end of which is hermetically sealed. The dark portion AB, represents mercury—which is retained in its position, by the pressure of the atmosphere. It is connected with the receiver, by a screw at the extremity P.—When the air has been so far rarified that it can no longer support a column of mercury, even so limited in height as AB, that fluid begins to descend. If the vacuum formed were perfect—which can never be the case—the mercury would ultimately stand at the same height both in DB, and AB.



23. The air pump enables us to prove the elasticity, &c., of the air, by many interesting experiments.—If porter, is placed under the receiver A, when the pressure of the atmosphere is diminished, the air which it contains, will convert it, to a greater or less extent, into froth.

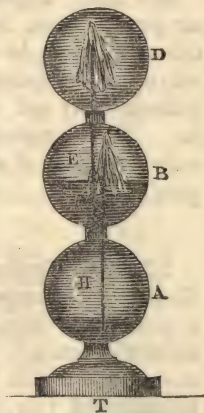
24. If an egg, which has a small aperture in its lesser end, is placed under the receiver, when the air is rarified, its contents will be forced out, by the expansion of the small air-bubble contained in the larger end;—but they will return again into the egg, on re-admitting the air into the receiver.

25. If a shrivelled apple is placed in the receiver, and the air is exhausted, it will cease to be shrivelled:—since the air within it will expand; but, on re-admitting the air, its plumpness will disappear.

26. If a lighted taper, or a living animal, is put into the receiver, the former will be extinguished, and the latter will die, when the air is exhausted.—Chemistry will, hereafter, teach the reason of this. Some animals expire immediately; others—such as frogs, survive a long time. These experiments are cruel; and should not be made, except when—from the increase of knowledge acquired—the amount of good more than counterbalances the pain they inflict.

27. The fountain represented, fig. 176, illustrates both the rarification, and condensation of air. It consists of three glass globes A, B, and D, united by necks, but having no communication, except through the tubes H, and P:—the globe B, has an opening at E. When the apparatus is placed under the receiver A, fig. 174, on working the pump, the air, in B, rushes out through the aperture E, until what remains having become so rarified, as that it can no longer counteract the pressure of the air, which is above the water in A, that fluid is forced up through the tube H, and continues to form a jet, in B, until its surface has descended below the lower end of H. On re-admitting the air into the receiver, it passes freely through the tube H, the upper end of which is above the water in B, but, presses on the latter, and forces it up through P—forming a jet in D, the interior of which contains only rarified air.

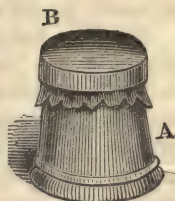
FIG. 176.



28. PRESSURE OF THE AIR.—The air has weight. For a flask will weigh less, when exhausted, than when full of air:—The weight of a cubic foot of air is found to be about 523 grains. The pressure of the atmosphere may be illustrated by a simple experiment.—A bladder is to be tied on the smaller end

of a strong glass receiver A, fig. 177, open at both ends, and ground at the larger, so as to fit, air-tight, on the plate of the air-pump. When A is exhausted, the pressure of the atmosphere, no longer counterbalanced by a pressure from within, will cause the bladder to burst with great violence, and a loud report.

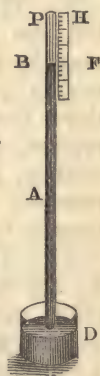
FIG. 177.



29. If the edges of two brass hemispheres, which have been fitted together so as to be perfectly air-tight, are united—but without being fastened in any way, they will continue to adhere when the air is exhausted from between them, and, with a force proportioned to their size. Hence, if they are tolerably large, it will be impossible for any one, by mere muscular exertion, to pull them asunder.

30. THE BAROMETER* is an instrument, intended to measure the pressure of the air, arising from its weight. It was invented by Torricelli, a disciple of Gallileo, early in the seventeenth century, in consequence of a doubt entertained by the latter, that the ascent of water in pumps was due to what was then considered to be its cause—"nature's abhorrence of a vacuum." Torricelli soon suspected the true reason, and, demonstrated it, by means of the barometer.

31. Its principle, and mode of action, will be understood from fig. 178. The glass tube A, about 33 inches long, and hermetically sealed at one end, is filled with mercury, and—the open end being closed with the finger—is inverted in a cup of mercury D:—the fluid in the tube immediately falls to some point B, the position of which depends on the pressure of the atmosphere. The empty space between P and B is called the *torricellian vacuum*.



32. Before the tube was immersed in the mercury, the surface of the latter sustained a pressure of about 15 lbs. to the square inch. But the pressure is now removed from over that part of it, which is within the tube—being transferred to the exterior of the hermetically sealed end of the latter. The pressure, therefore, on the surface within, is no longer equal to that which is outside:—hence [mech. 107] motion ensues, and the mercury is forced up into the tube by the atmospheric pressure, which is the greater; and it will continue to rise until, by its weight, it exactly counterbalances the action of the column of air which it has replaced. As the pressure of

* *Baros*, weight; and *metreo*, I measure.

the atmosphere is variable, the column of mercury sustained by it, must be variable, also.

33. The barometer gauge [20] is exactly the same in principle, as the barometer: but its upper extremity, instead of being hermetically sealed, is connected with the receiver of the air pump; and, as the exhaustion proceeds, the mercury rises within it. If the vacuum in the receiver could be made as perfect as the torricellian, the mercury, both in the barometer and in the barometer gauge, would stand at the same height. But, since, as we have seen [19], some air still remains in the receiver, the pressure on the surface of the mercury within the gauge, is never completely removed. Hence, the column within is diminished—the pressure inside the tube, being made up, partly of the pressure of the mercury, and partly of the pressure of the air which still remains above it; and the sum of both is just equal to the pressure of the mercury alone, in the barometer. The amount of exhaustion in any vessel, is measured by the number of inches of mercury, which are sustained in opposition to gravity.

34. It is evident that the real height of the mercury, in the barometer, is its height above the surface of the mercury in the cup. Hence, as the latter is raised, by the descent of mercury from the tube, and *vice versa*, in good barometers, there is always some means of accurately comparing the level of the mercury in the tube, with that in the cup.

35. The barometer has been made to assume many forms; but the simplest is found to be the best. Every attempt to magnify the space, through which the mercury ascends or descends—which is about three inches, the mean pressure being thirty inches—seems to be accompanied with a sluggishness of motion, or some other inconvenience, which diminishes the sensibility; and, therefore, philosophers content themselves with carefully constructed instruments, of the ordinary kind—the *vernier* being used to assist them in their observations.

36. The *Aneroid barometer** was proposed as a substitute, for the mercurial, by M. Conte, in 1798: but it is said that the effect produced upon the instrument by changes of temperature, caused it to be abandoned, by its inventor. It consists of a thin metallic vessel, in which the air has been highly rarified, and which alters its shape, as the pressure of the external air varies. This change of shape is indicated, and measured, by a suitable contrivance. Though it is difficult to prevent alteration of temperature, &c., from interfering with the accuracy of this instrument, it has been found to agree very much with the ordinary barometer.

* *A*, privative; and *aër*, the air. *Gr.*

37. As we ascend from the surface of the earth, the pressure of the air, and, therefore, the height of the mercury in the barometer, diminishes; and the diminution is found to be, about one inch for every 992 feet of ascent. A knowledge of this enables us to measure the height of mountains.

38. Let the barometer, for example, stand at a given height on the plain; and, at the same time, four inches lower, upon the top of a mountain:—we may conclude the height of the mountain to be $4 \times 992 = 3,968$ feet. In this experiment, inaccuracy will arise from not taking into account difference of temperature, which causes the bulk of the air to change, and consequently alters its density. Change of temperature is found to produce nocturnal and diurnal oscillations of the barometer. The rise and fall of the ocean appears, also, to affect it—since a variable base is given to a large portion of the atmosphere.

39. The air on the top of high mountains is sufficiently rare to affect respiration—to occasion a loss of muscular strength—to diminish the intensity of sound—and to make a fire be kindled, and maintained, with difficulty. Since the column of air in the torrid zone is higher, on account of the rarification caused by heat, the diminution of barometric pressure, consequent on distance from the general surface of the earth, does not proceed so rapidly as in the temperate, or frigid zones.—Hence it has been found that the barometer does not sink more than half as much for a given number of feet of ascent in the torrid, as in the temperate zones.

40. We may with equal facility, estimate depths, by means of the barometer. When the shaft of Monkwearmouth colliery—the deepest, perhaps, in the world—had reached to 1,500 feet below the level of the sea, the barometer stood, in the lowest part of it, at 32·280 inches, while one at the surface was at 30·518.

41. The barometer is, sometimes, but inaccurately, called a *weather glass*. Undoubtedly, change of weather is generally accompanied by some change of atmospheric pressure: but the present state of our meteorological knowledge does not enable us to say, with certainty, what the corresponding changes are. It is clear that the indications, affixed to many barometers, and which are intended to mark the *precise* variations of weather, corresponding to the different heights of the column of mercury, are not to be relied on. For, if they were accurate, the weather should be different on the top of St. Paul's dome, and at the pavement around the church;—since the indications of the barometer would be different, above, and below. The only fact, well ascertained, seems to be that, in very fine weather, the mercury is generally high; in wet weather, low;

and in variable weather, changeable. The barometer is low, also, in great storms—of which we had a remarkable instance in the disastrous hurricane of January 6, 1839; on which occasion, the barometer was remarked to stand lower than at any previous observation. In these countries, the barometer varies about three inches: at Náples, about one inch: and within the tropics, scarcely at all.

42. The state of the barometer must be taken into account, when we estimate the volumes of gases and vapours [hyd. 61, and 64]. For, since their bulk varies inversely as the pressure [12], we cannot compare different volumes, with accuracy, unless we compare them, when under the same pressure—or make the necessary correction. Thirty inches, the average height of the mercury, is the standard adopted. “The volume at any one pressure, is equal to the volume at any other multiplied by its corresponding pressure, and divided by the pressure belonging to the required volume.”*

EXAMPLE:—When the barometer stands at 27 inches, the volume of a given quantity of a certain gas is 38 cubic inches:—what would be its volume, if the barometer stood at 30 inches?

$$\frac{27 \times 38}{30} = 34.2 \text{ cubic inches, the required volume.}$$

43. The actual density of a given portion of the atmosphere depends on its specific gravity—which is affected by heat, cold, &c. Changes in the density of the air are indicated by the *manometer*,† or *manoscope*.‡ These instruments have been constructed in various ways.—Boyle formed one, which he called a “statical barometer,” with a bubble of very thin glass about the size of an orange, balanced very delicately when the atmosphere was at a mean density. It descended if the air became lighter, and ascended if it became heavier.

44. PUMPS are of various kinds; but from what I have said of the condenser and air pump, it will be easy to understand their construction.

The house or suction pump.—The barrel A, fig. 179, is connected with a tube T, by the valve D: a piston—also, having a valve—works water-tight in A: and both the valves open upwards. When the piston is raised, by means of the handle H, the valve which it contains is closed, and the air below it, is rarified [19]: after which, the air—or, at the end of a few strokes, the water—in T, on account of the external atmospheric pressure acting upon the surface of the water in the well or cis-

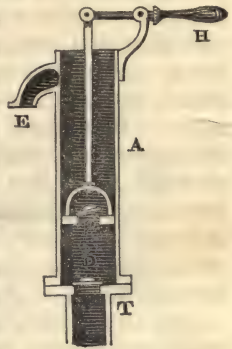
* Let a , be the volume, with a pressure b : and c , the volume, with a pressure d . Since the pressures are, inversely, as the volumes, $a:c::d:b$. Therefore $a = \frac{cd}{b}$: and $c = \frac{ab}{d}$.

† *Manos*, rare or subtile: and *metro*, I measure. Gr.

‡ *Manos*: and *scopeo*, I examine carefully. Gr.

tern connected with T, raises the valve D, and passes into the lower part of the barrel A. On depressing the piston, its valve is raised by the water under it, which passes into the upper part of A. When the piston is next raised, the water over it ascends higher, and, ultimately, issues out through the spout E—while an additional quantity flows through D, into A: and thus, as often as the piston is raised and depressed, the same effects are produced, if the proper supply is maintained by the pipe T.

FIG. 179.



Sometimes there is no valve at D; nevertheless, the water rises through P, when the piston is depressed—the latter being made to descend so rapidly that the fluid has not time to flow down before it.

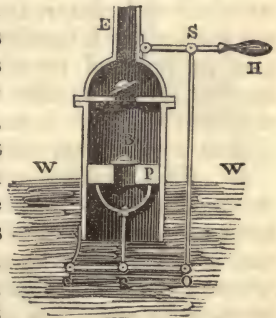
45. Since it is the pressure of the air that causes water to rise in a pump, the height to which it will ascend depends upon that pressure. When the barometer is at 30 inches, water will rise to the height of about 33 feet:—for a column of mercury, 30 inches, is nearly the same weight as a column of water 33 feet high.

46. Water may be raised to a considerable height by increasing the length of that part of the barrel A, which is above the piston.—In such a case, however, atmospheric pressure has nothing to do with the additional distance, through which the water is lifted.

If the piston rod is very long, it is found to bend, unless there are guides within the barrel, at certain distances.

47. *The lifting pump.* Water may be elevated, through a considerable height, by a modification of the suction pump, represented, fig. 180.

FIG. 180.



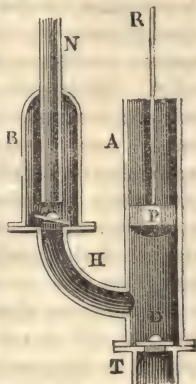
When the piston P, is raised, by means of the handle H—the effect of which is transmitted, through the rod SO, to CO turning on C—the air, under it, is rarified, and the water ascends into the lower part of the barrel B. On depressing the piston P, the air—or, after a few strokes the water—lifts the valve in P, and ascends above it: when the piston is next raised, the fluid over it ascends still higher, and, ultimately, passes into the pipe E—being prevented from returning, in each case, by the respective valve falling down into its seat.

48. *The forcing pump* may be understood from fig. 181. It

consists of a barrel A, in which the solid piston or *plunger* P, is movable up and down. A, communicates with the pipe T, by the valve D; and, with the air-vessel B [16], by the pipe H, which, also, is closed by a valve:—both valves open upwards. When the piston is raised, the air under it is rarified, since the valve in B is closed: and air—or, after a few strokes water—rushes up from the pipe T, through the valve D. When the piston is depressed, D closes, and the air or water, as the case may be, rushes through the other valve, into B; and, ultimately, passes up through the pipe N.

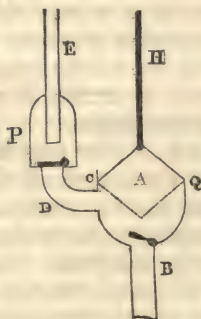
The air-vessel B may be omitted, when a constant jet, from N, is not required.

FIG. 181.



49. A very simple pump, applicable in some cases, may be understood from fig. 182.—The vessel A is closed above by CQ, a piece of oiled cloth, vulcanized Indian rubber, &c. When this is drawn up by the handle H, the space in A being enlarged, a partial vacuum is formed, and fluid rushes in through the valve which is over B. When H is depressed, so that the cloth, &c., assumes the position indicated by the dotted lines, the space in A being diminished, fluid ascends into P through the valve which is over D: and ultimately passes through E.

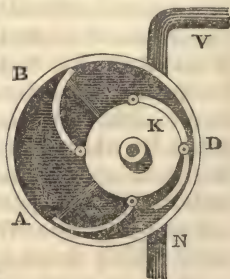
FIG. 182.



50. The *fire engine* consists of two pumps, standing in a cistern, and connected with an air-vessel. The cistern may be supplied with water, by hand, or by a tube, &c. The pumps are worked with handles, which extend along, at each side, and may be grasped by several persons at once. The water is conveyed, by a flexible tube and nozzle, to the spot where it is most required. The details may be variously arranged.

FIG. 183.

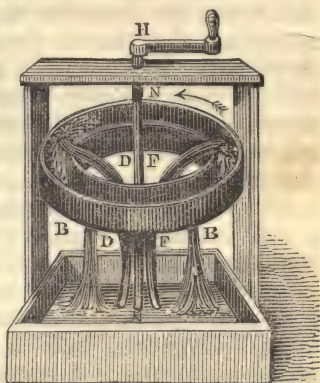
51. The *eccentric pump* consists of a drum ABD, fig. 183, having within it a solid cylinder, which is of the same length, but of little more than half the diameter of the drum. The flaps KK, &c., which are of the same curvature as the inner cylinder, are distended, during the revolution of the latter, by wires crossing each other at, and passing freely through the solid



cylinder.—As they open, the vacuum produced inside of them, is supplied by the feed-pipe N: when they close, the water is forced up the pipe V. It is extremely difficult to keep the chambers of this pump from leaking into each other.

52. *The centrifugal pump* consists of tubes DD, and FF, fig. 184, united to, and turning on a vertical axis NN. When they are made, by means of the handle at H, to revolve rapidly, the water is thrown out at their upper extremities by centrifugal force [mech. 112]; and the vacuum produced, causes the fluid to rush up into them, from the cistern, &c. The machine is always ready to act, on account of the water being retained in the pipes, when at rest, by valves—which are opened by the centrifugal force imparted to the water, during its rapid motion.

FIG. 184.

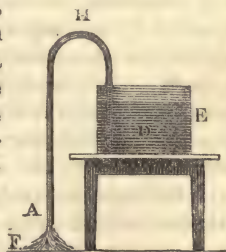


A very effective centrifugal pump, which seems to answer well for moderate heights, is constructed somewhat like the tangential turbine [hyd. 132]. Being made to revolve with great velocity in the direction of the arrow, fig. 164, a considerable quantity of water passes in at the centre from a pipe, and is thrown out at the circumference. Gravel, &c., produces no injury to the machine.

53. *SYPHONS* are bent tubes of glass, metal, &c., such as AHD, fig. 185—one of the legs being shorter than the other.

If AHD, is filled with any fluid, and—its longer leg HA being closed with the thumb, &c.—is immersed in the fluid contained in the vessel E, on removing the thumb, a stream will issue from A, and will continue to run until the surface of what is in the vessel, is below the extremity of the leg HD. For, what is in AH, descends by the force of gravity: so that a vacuum would be produced in that leg, if the atmosphere, acting on the surface of the fluid in E, did not cause it to ascend through DH.

FIG. 185.



The velocity with which the liquid escapes through A, depends on the difference between HA, and that part of HD, which is above the surface of what is in E. When they are equal, the two columns will be in equilibrio: and the fluid will remain at rest.

54. The syphon is extremely convenient for decanting liquors; and, the more easily to prevent the fluid from escaping before it is immersed, a cock is sometimes placed at the extre-

mity of the longer leg. When used by chemists, &c., it is occasionally constructed as represented, fig. 186. A small tube HP, having a bulb at E, is inserted into the lower extremity of the longer leg BA. When BD is immersed in the fluid to be drawn off, A being closed by the thumb, the air in HP is drawn out—by sucking with the mouth at H. This exhausts ABD, and the fluid fills the syphon, so that, on removing the thumb from A, it immediately flows out. If reasonable caution is used, the bulb E prevents any danger of the fluid being drawn into the mouth—which, in many cases might be attended with inconvenient, or even dangerous consequences.

FIG. 186.

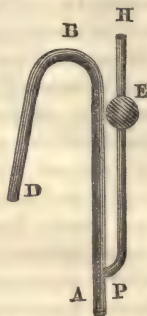
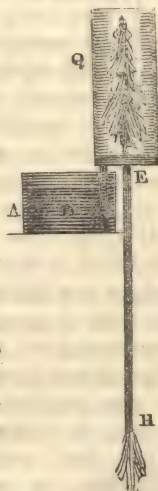


FIG. 187.

55. *The syphon fountain* may be formed with a tall bottle, or a glass cylinder Q, fig. 187, which is closed above, and has tubes fitted air-tight into a cork, inserted in its lower extremity. If a small quantity of water is introduced into Q, and the shorter tube is placed in fluid contained in the vessel A, the air in Q will be rarified—on account of the fluid, which is in it, flowing down through EH: and the atmospheric pressure, acting on the surface of what is in A, will force it up through the shorter tube—a jet being formed, which will continue until the extremity of that tube is no longer immersed. This instrument is merely a syphon, somewhat enlarged in one portion.



56. SOUND, is a series of vibrations of any sonorous body, communicated to the ear by any *medium* or intermediate substance—generally by atmospheric air. A fine membrane, called the *tympanum* or drum, stretched across a cavity of the ear, is the part most affected by sound—though it appears that* this is not indispensable to hearing. If the vibrations of the sonorous body are too slow or too rapid, they will be imperceptible. Under ordinary circumstances, sound cannot be produced without the presence of air—as we may demonstrate experimentally, by attempting to ring a bell in an exhausted receiver.

57. CONDUCTION, &c., OF SOUND.—Some bodies are found to transmit sound better than others—thus, wood better than air. This may be proved, by placing the ear at one extremity of a long beam of timber, and causing the other to be struck gently with a key:—the sound, transmitted by the timber, will be heard with the greatest distinctness. Iron conducts sound still better

* Phil. Trans. 1800, &c.

than wood.—M. Biot found, at Paris, that a watch, which was made to tick, at one end of a cast-iron pipe, was heard perfectly well at the other; although the pipe was three or four miles in length. Communication is often maintained between very distant apartments, by means of tubes. And deaf persons have frequently been able to enjoy the pleasures of music, by holding in their teeth a metallic substance resting on the musical instrument.

58 *Velocity of sound*.—Whatever the intensity, quality, or pitch of sound, the velocity of its transmission through the same medium never alters. The following table exhibits the speed, with which it is transmitted, through certain substances, the rate which it passes through air being considered as unity:—

Through distilled water,	4·5,	according to Laplace.
„ sea-water,	4·7,	„ Ditto.
„ tin,	7·5,	„ Chladni.
„ silver,	9·0,	„ Ditto.
„ cast iron,	10·0,	„ Biot.
„ brass,	10·5,	„ Laplace.
„ copper,	12·0,	„ Chladni.
„ wood,	11·0 to 17·0,	„ Ditto.
„ hammered iron,	17·0,	„ Ditto.

59. The velocity, with which sound is transmitted by the air, depends on the state of the latter. According to Sir J. Herschell, it travels in dry air, when its temperature is 32°, at the rate of 1,089 feet in a second. Its velocity has, however, been very differently estimated by different persons. When conveyed by aeriform bodies, its velocity is inversely as the density of the medium—temperature and pressure being constant. When the height of the column of mercury in the barometer is altered—the temperature being constant—the velocity is not changed: for, then, both elasticity and density are equally increased, or diminished. When the temperature is increased, or diminished—the barometric column being unchanged—the velocity is increased, or diminished: for the elasticity, but not the density, is increased, or diminished. A rise in temperature of one degree, increases the velocity of sound 1·14 feet per second. An equal decrease of temperature produces a contrary effect.

60. The different rates, at which different bodies transmit sound, sometimes causes two sounds to be heard, instead of one—so as to produce the effect of an echo. Thus, if a cannon is fired across a frozen river, its report will be conveyed first by the ice, and afterwards by the air. Or, if the top of a wall is struck by a hammer, the sound will be heard twice at the bottom of it:—first, when conveyed by the wall; and next, by the air.

61. The *intensity of sound*, or its “loudness,” depends, not on its pitch or its quality, but on the amplitude of the oscilla-

tions which constitute it: and is inversely proportional to the squares of the distances between the sounding body and the ear. It is affected by the rarity, or density, of the atmosphere.—On a high mountain the voice is scarcely audible; in the diving bell, under water, it is disagreeably loud. Its intensity is diminished by currents of air.—The voice can scarcely be heard at the distance of a few yards, during a strong contrary wind.

62. The thermometric, and hygrometric states of the air, affect the intensity of sound. When the air is calm and frosty, it is often heard to a considerable distance.—In Captain Parry's third polar expedition, Lieutenant Forster held a conversation across the harbour of Port Bowen, the distance being a mile and a quarter.

63. The intensity of sound is affected, also, by its original direction, and by the nature of the surface over which it passes. It is greatly lessened, when the sound is transmitted through media of different conducting power. Hence, the destruction of the homogeneity of the air, by alteration of temperature, is unfavourable to the transmission of sound:—and it is transmitted better by night than by day. Hence, also, a tall glass half filled with champagne, &c., cannot be made to ring, as long as the effervescence continues.

64. Sounds are diminished in intensity, by passing from solid to fluid, and still more to gaseous substances. Some bodies produce only a weak tone, from being incapable of imparting their vibrations, properly, to the air. Their effect is, however, heightened by *resonance*, that is, by their communicating them to another solid body which, having a large surface, more easily affects the air:—hence, the use of the *sounding board* in many musical instruments. Bringing the vibrating body, such as a tuning fork, &c., before a tube of proper length, renders the sound much more intense.

65. Hydrogen gas is almost as unfavourable to the transmission of sound as a vacuum. Hence the voice becomes small, when it is breathed—the lungs being filled with it.

66. As the air is compressed, during the undulations of sound, its temperature is raised: and the heat absorbed during the next rarification, is not equal to what was given out in the preceding compression—air being a bad conductor.

67. Sounds excited in air, are heard very indistinctly by a person immersed in water; but, if excited in water, they are conveyed to a considerable distance.—A bell, struck under water, was heard across the Lake of Geneva; a space of about nine miles. Solid substances cause but little interruption to sounds transmitted by the air: but render them almost inaudible, if transmitted by water. When all the circumstances happen to be very favourable, sounds are, occasionally, con-

veyed over very large distances.—Thus the cannonading at Waterloo, was heard in Dover.

68. *The quality of sound* is due to causes which are but little understood. Every one, however, has remarked the difference between the very same note, played on different kinds of instrument—or even on different instruments of the same kind.

69. **MUSICAL SOUNDS.**—The difference between ordinary, and musical sounds, consists in the greater rapidity of vibration of the latter. The more rapid the vibration, the higher the pitch.—This is exemplified, by causing a metallic toothed wheel, about one foot in diameter, to revolve, and making the teeth, during revolution, strike against the edge of a card; when the velocity reaches a certain point, a humming noise will be heard; and, as the speed is increased, the sound produced will ascend through the scale. It is probable that the ancients used the expressions “high,” and “low” tone, in a sense different from ours.

70. **THE GAMUT.**—When a musical note is sounded, it is accompanied by others, which are called its *acute harmonics*.—If the note is sufficiently deep, these will not be too high to be appreciated by the ear. The range of hearing, generally, though not always, includes nine octaves; but, as Dr. Wolaston remarks, the hearing of some animals may commence where ours terminates. The acute harmonics, which accompany the fundamental note, are its twelfth and seventeenth major—or the octave fifth, and double octave third above. Bernouilli believed, and it has been since established by experiment, that harmonies arise from subordinate vibrations of the strings, &c.

71. We find, from this property of musical sounds, that the notes, which constitute the gamut, have not been selected by chance, nor by the caprice of taste, but have been marked out by nature herself; and that in each key there can be neither more nor less than a certain number of flats, sharps, or naturals.—If we examine the key of C, for example, we shall perceive that all its notes are harmonics of some one, or more, of the rest; and the entire scale will be formed from F, C, and G, three successive fifths—which may be arranged C, F, G, because, as far as harmony is concerned, a note and its octave may be considered the same. These three notes form, what are called, the “key-note,” the “sub-dominant,” and the “dominant;” and their harmonics will give us all the notes in the key of C—substituting as we may, for the reason just given, the fifth, &c., for the octave fifth, &c. Thus

C	gives, as harmonics,	E and G
F	“	A “ C
G	“	B “ D

Which, placed in order, are C, D, E, F, G, A, B.

72. If we take the key of G, as another example, we shall learn in what manner sharps are obtained. Three fifths in succession will be C, G, and D—or G, C, D. And their harmonics will be—

From G, B and D

„ C, E „ G

„ D, F „ A

Which, placed in order, are G, A, B, C, D, E, F.

But in this key, the F is not the same as that in C. For, in the key of C it was natural, while in the key of G it is sharp. The reason of this will be obvious, if we remember that harmonics are a third and fifth *major*: but the major third is the fourth semitone; and the perfect fifth, the seventh semitone from the principal or fundamental note. Hence, the major third of D must be at the distance of two full tones from it, while there are only one and a half between it and F natural—which, therefore, will be the *minor* third: for between D and E there is a whole tone; but between E and F, only half a tone. The major third of D will, consequently, be half a tone higher than F natural—that is, it will be F sharp.

73. We shall not find it hard to conceive that the harmonics and principal note may all sound together, if we call to mind that it is as easy for undulations of various velocities to co-exist in the air, as that waves, in water, should pass over each other, and yet remain perfectly distinct—which occurs, if they do not differ too much in size.

74. We cannot change from one key to another without *modulating*, as it is called—that is, making proper preparation. For the ear must not change abruptly from sound to sound, since each succeeding sound, to give us pleasure, must be heard, more or less distinctly, as an harmonic of the preceding. Hence—except we pass from a major to a minor key, or *vice versa*, which we may do, because, in such a case, a sufficient preparation is made—we cannot, strictly speaking, increase or diminish the number of flats or sharps, by more than one at a time.—We may, however, increase or diminish them by one. For, taking the key C as an example, its principal notes are F, C, and G: but the part of the scale of C, which is between C and G, belongs, also, to the key of G, the principal notes of which are C, G, and D. Hence, while we are between C, and G, we may, without offending the ear, choose between either key; and pass, if we please, from one to the other:—if we choose the key of C, the F must be natural; if that of G, it must be sharp. The other methods of modulation depend on similar principles.

75. The preparation of the ear, for the succeeding notes is the great secret of melody. The ear can appreciate sounds

which we are not able to describe; for sensation does not cease, so soon as the cause which produced it. Thus, if a stick, lighted at one extremity, is whirled round rapidly, we see a ring of fire:—not because the fire is in different parts of the circle at once; but because the sensations it produces, when in different parts, are co-existent, though their causes are successive. In the same way, the string, or the pipe, may have ceased to produce the sound, although the note and its harmonics have not vanished from the mind. Two rapidly succeeding notes may, therefore, be co-existent in the ear; and cannot be pleasing, unless, to a greater or less extent, they harmonize. Hence, though melody is a “succession,” and harmony, a “union” of sweet sounds, it is certain that both derive the sources of the pleasure they impart, from very similar causes. Those nations which, like the ancient Irish, used stringed instruments, the construction and material of which rendered it likely that, even in melody, one note should not entirely cease, until another had commenced, will be found, in their most agreeable airs, to have made them successive emphatic notes near harmonics of the preceding—very frequently thirds, fifths, or octaves: the pleasures both of harmony, and of melody are, by this means, to a certain extent united.

76. If two notes, each making an integral number of vibrations while a third makes but one, are sounded together, we shall, under favourable circumstances, hear, also, that third note—which is called a “grave harmonic.” The reason is obvious; a strengthened vibration occurs, when the vibrations of the two notes coincide; and this being more effective than the other vibrations, gives the sensation of a distinct one, at intervals corresponding to the vibrations of the third note.

77. SYMPATHY.—If two instruments are tuned in unison and placed near each other, one cannot be sounded, without producing the corresponding note of the other: this is very evident with a stringed instrument—a pianoforte, for instance. Such an effect is termed “sympathy,” and can be easily exemplified with a violin and piano. We shall find, on sounding any note of the former and suddenly causing it to cease, that—if the damper has been previously raised—the corresponding note of the latter will be heard. This principle may be further developed if, by means of the pedal, we raise all the dampers, and place pieces of paper across the third, fifth, and octave of the note we sound on the violin:—the pieces of paper will be thrown off the strings, by their being made to vibrate sympathetically.

78. If we put pieces of paper on the centres of the two halves, and on the middle of any string of a piano, and sound the note an octave below on the same instrument, the

pieces on the centres of the halves will be thrown off, but the piece on the middle of the string will not be disturbed. This shows that it has divided itself into two halves, each of which sounds in unison with the string which was struck; while there is in the middle a *node*, or point completely at rest. These experiments may be varied; but their results can be anticipated, from what I have said.

The nature of sympathy enables us to understand why an instrument, which is well tuned—independently of its accuracy—has a finer tone:—the various notes, being more nearly harmonics, strengthen the effect of each other.

79. Sympathy is not confined to musical instruments; it seems, to a greater or less extent, to affect every substance in nature.—That is, every substance has a rate of vibration, proper to itself; and is easily set in motion, provided anything, vibrating at its own rate, is sufficiently near. Wine glasses, and even mirrors, have been, from this cause, sometimes broken by singers; and, as Boyle remarked, we frequently perceive a book, seat, &c., to vibrate at certain notes. The vibration is communicated by the air, and gradually increases in strength—the effect being due, not to the loudness of the note, but to its coincidence with the rate at which the body naturally vibrates. If we wet the edge of a drinking glass, and rub the finger round it, the vibration—at first extremely small—may, by constantly receiving new impulses, increase to such an extent, as that the glass will fly in pieces. These facts explain the breaking down of a suspension bridge, some years ago, at Manchester. Soldiers were passing over it—at first, in disorder, and without any injurious effect; but the band having begun to play, they commenced a regular march, the time of which, unfortunately, corresponding with the rate of vibration of the bridge, the latter gave way, and the soldiers were precipitated into the river. Thus, it is perfectly possible that a storm—or even, under certain circumstances, the continued effort of a single individual, might destroy a bridge capable, when at rest, of sustaining an enormous weight.

80. Ellicot remarked, that two clocks fastened to the same board, or standing on the same pavement, will beat together, though, separately, their rate of going may be different. The pendulum of a clock in motion, has been known to cause another, at rest, to vibrate, and, at its own rate. It has even been remarked by clockmakers that, if the heavy weight of a large clock passes in front of, and very near the pendulum, it interferes with its rate of vibration:—the weight will begin to oscillate of itself, though a board is interposed between them; and their mutual action will decrease, according as they become more distant from each other.

81. We avail ourselves of this property of bodies, to cause the

very large pipes of organs to speak rapidly.—The columns of air within them being considerable, time is required to put them in motion [mech. 6]: but this is greatly abbreviated, if we sound, at the same instant, a small pipe, some octave above the great one.

82. We cannot alter the rate of vibration, which is proper to a given body.—If one end of a string is attached to a wall, &c., and the other is held in the hand, whatever amount of force we use, we cannot make it vibrate with greater than a certain rapidity—dependent on its length, and thickness. When we attempt to increase this rate, the string will form itself into parts, each of which will vibrate separately; and the greater the force we use, the smaller these parts will be. From this cause, an Eolian harp, having but one string, is capable of giving a variety of tones—according to the strength of the wind. When we blow gently into a pipe, we sound its fundamental note; but if we blow with increasing force, we produce the twelfth, fifteenth—or double octave: and the seventeenth, nineteenth, &c., will follow in succession. It is on this principle that the various notes are obtained, in certain instruments.

83. TEMPERAMENT.—The time of vibration of a given body depends on its nature. We shall consider only strings and pipes; but the same laws govern the other sources of musical sound. The time of vibration of a string depends on its length, thickness, and tension conjointly.

84. If the tension and thickness are constant, it depends on the length. Half the length will give a vibration twice as rapid; double the length a vibration half as rapid, &c. Hence, the octave above a given note will require half, and the fifth above, two-thirds of the string which produces that note.

85. We may arrive, by calculation, at the seventh octave above, either by fifths or octaves; but the values we obtain will be different. Taking C, as an example, calling it unity, and calculating by fifths, we find the following values for the different successive fifths—

C = 1	C# = $\frac{128}{2187}$
G = $\frac{2}{3}$	G# = $\frac{256}{6561}$
D = $\frac{4}{9}$	D# = $\frac{512}{19683}$
A = $\frac{8}{27}$	A# = $\frac{1024}{59049}$
E = $\frac{16}{81}$	E# = $\frac{2048}{177147}$
B = $\frac{32}{243}$	B# = $\frac{4096}{531441}$
F# = $\frac{64}{729}$	C nat. } = $\frac{4096}{531441}$

The string, or pipe, corresponding to each note, will be, in length two-thirds of that belonging to the preceding note.

Calculating by octaves, we find the following values for the different successive octaves—

$$C = 1 \cdot C = \frac{1}{2} \cdot C = \frac{1}{4} \cdot C = \frac{1}{8} \cdot C = \frac{1}{16} \cdot C = \frac{1}{32} \cdot C = \frac{1}{64} \cdot C = \frac{1}{128} \cdot C$$

The string or pipe corresponding to each note, will be, in length, one half of that belonging to the preceding note. The values obtained for B \sharp and C nat, which are the same note, in most instruments, will be as $\frac{4096}{331441} : \frac{1}{128}$; that is, as $\frac{524288}{68024448} : \frac{531441}{68024448}$; or as 524288:531441.

86. This difference of value for the same note, according as we calculate or tune by fifths, or by octaves, accounts for the variation of effect, if an organ, piano, &c., is tuned by fifths, in one case, and by octaves, in another. For, if the instrument is in tune, by fifths, it will be out of tune, by octaves.—The adjustment of the interval, so as to cause the effect to be as little perceptible as possible, is called “temperament:” it is only a choice of evils, however, since most of the notes are thrown by it, to a slight extent, out of tune. To understand the nature of the correction made in the intervals, that the inconvenience arising from this difference in the values of the same note, or as it is technically termed, the “wolf,” may be avoided, it must be observed that, the more perfect a chord is, in its own nature, the more intolerable it becomes, when inaccurate. But octaves are more perfect than fifths, since their vibrations more frequently correspond: and, hence, if *either* fifths or octaves *must* be out of tune, we prefer making the former inaccurate—the inaccuracy being, however, so divided, as that it becomes scarcely perceptible. In such a case, we consider notes as the same—for instance, A sharp and B flat—which are really different; but we, by this means, avoid multiplying the notes to an inconvenient extent. For the greater accuracy of the intervals, however, instruments have been constructed—among others, the organ in the Temple Church, London, the double action pedal harp, &c.—in which, these, and notes similarly circumstanced, are made, in reality, different.

87. The following are the rates of vibration, and relative lengths of the different notes in the scale—

Names of the Notes,	A	B	C	D	E	F	G	A
Relative Number of Vibrations, .	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Relative Length of Strings, . .	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

An open pipe, 32 feet in length, will make 32 semi-vibrations in a second; and will produce the deepest tone we use in music. The sharpest tone requires about 15,000 vibrations in a second.

88. TUNING OF PIPES, STRINGS, &c.—The pipes of musical instruments owe their rates of vibration not to the material of which they are formed, but to their length. Their cross section has but little effect—except as to the quality of their tone. Shortening a pipe renders the sound it gives more acute.

89. Pipes, when stopped by a plug, produce a note which is an octave deeper than that which is emitted by others of

the same length, but open : because, in the former case, the vibrating column of air is twice as long.—For it is found that the column in the open pipe divides itself into two equal parts, each of which vibrates separately. A stopped pipe is tuned, by pushing in, or drawing out, the plug—according as the tone is too grave, or too acute.

90. Increasing the length, or thickness, of a string, causes it to yield a deeper tone ;—the depth is, however, more rapidly increased, by adding to its thickness, than to its length. It is not the absolute, but the “vibrating” length which is to be taken into account : that is, the length between the two points, at which it comes into contact with other bodies—and beyond which its vibrations do not extend.

91. The number of vibrations made by a given string, is as the square of the force with which it is stretched.—Thus, if it is stretched by a certain weight, doubling the latter, will produce four times the number of vibrations.

92. When rods, or bars of metal are fixed at one end, and made to vibrate, the number of vibrations is inversely as the squares of their lengths, and directly as their diameters. Thus, a bar half the length of another, will give four times as many ; but a bar twice as thick, will give twice as many vibrations.

93. Deep tones are, sometimes, produced by very simple means.—A spiral spring of tolerably thick steel wire, when struck, emits a sound very like that of a large bell ; and is often used in time-pieces, &c., which strike the hours. If a poker is suspended by a cord, the ends of which are held in the teeth—or one of them in each ear—and struck with a metallic substance, extremely deep sounds will be heard.

94. Chladni discovered that curious figures may be formed with sand, scattered on a pane of glass, which is fixed in a vice, &c., if the bow of a violin is drawn across the edge of the glass. It is known that these figures depend on currents of air, set in motion by the vibration of the glass ; and that their peculiar form arises from the relative position of the fixed point, and that across which the bow is drawn. Galileo remarked that a bristle vibrates, when placed on the sounding-board of a musical instrument. If paper, or parchment, is stretched over the mouth of a large bell-shaped tumbler glass, and fastened at the edges, while wet, with gum, &c., sand on its surface will assume the figures of Chladni, when it is held beneath a plate of glass, under which a bow is drawn.—The paper, &c., should, as soon as it is dry, be varnished, to prevent its being affected, by atmospheric changes. This instrument is so delicate, that it will be acted upon by sounds that are inaudible. Notes played near it, produce upon it a powerful effect—which depends on its position with reference to the musical instrument. The

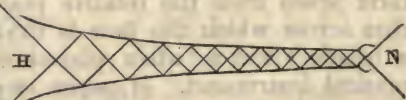
besieged have, sometimes, ascertained, in what direction a counter mine was being worked, by sand scattered on a drum-head.

95. REFLECTION OF SOUND.—Sound, when reflected, follows the laws of perfectly elastic bodies [mech. 136], making the angles of incidence and reflection equal. Reflected sound is called *echo*. The velocity of direct and reflected sound, is the same. Hence, as we know the rate at which it travels [59], if we know how long it has been moving, we can easily tell the distance of the reflecting body: for it will always be equal to the number of seconds, multiplied by $\frac{1089}{2}$. As the sound has, both to go to, and return from, the reflecting body, the distance of the latter is half that through which the sound has passed.

96. It is necessary for the production of echo, that the direct and reflected sounds shall not occur, at too small an interval—or [75] they will form but one sensation in the ear. Experiment shows, that the direct, and reflected sound will not produce separate sensations, if the reflecting body is at a less distance, than about 57·1 feet; for sound will travel twice that distance in the tenth of a second, which is the smallest interval between two successive impressions, forming distinct sensations.—Such an echo will give only a monosyllable. There are some very remarkable echoes: among others, that at Woodstock Park, which is said to repeat, very distinctly, 17 syllables in the day, and 20 at night. There is, also, a very fine echo, at Killarney.

97. CONCENTRATION OF SOUND.—Sound may suffer reflection, in such a way as to be concentrated to certain points, at which it will be distinctly heard, though, otherwise, but slightly, or not at all audible.—This is the principle of whispering galleries, the most celebrated of which is in the dome of St. Paul's, at London. It is said, likewise, to be the principle of the hearing trumpet, used by deaf persons:—the sound received at the wider end H, fig. 188, is condensed and concentrated at N, the narrower, which is placed next the ear. Also, of the speaking trumpet, which is of the same shape, but receives the sound at its

FIG. 188.

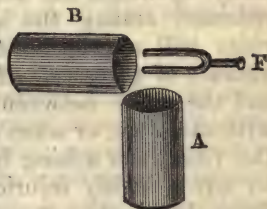


lesser end.—The air at the mouth of the instrument is affected by an impulse, which is as much greater than it would have been, in ordinary circumstances, as the surface of the air at the mouth of the trumpet, is less than the surface of a sphere having the trumpet for radius. Leslie, however, and others, appear to have proved that the trumpet has no other effect than giving to the air, as it were, a greater density, by preventing it from escaping with facility:—which enables the organs of the

voice to act more powerfully upon it. The confined air of narrow passages, &c., increases the intensity of sounds, for the same reason. If the effect of the speaking trumpet, &c., were due to reflection, much would depend on the shape of its surface. But this is not the fact; for Hassenfratz showed, at Paris, that a cylindrical trumpet conveyed to the ear the ticking of a watch, placed in its mouth, as well as a conical one.

98. INTERFERENCE OF SOUND.—Sound being a vibration of the air, we can easily conceive that two sounds, the vibrations of which happen to be exactly opposed to each other—either individually, or at certain corresponding intervals—should, to a greater or less extent, produce silence; which is found, by experiment, to be the case. For, if we tune two large organ pipes nearly in unison, when they are sounded *together*, certain intervals of silence will be perceived; and arise from this cause.—We may illustrate the interference of sound, by a tuning-fork F, fig. 189, and two cylinders of glass A, and B. If the fork, while in a state of vibration, is placed over the mouth of the cylinder A, a sound will be heard; but if B is, at the same time, held at right angles, the sound will cease.—The vibrations of the two glasses destroy each other.

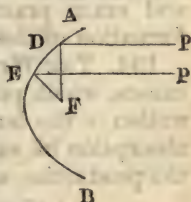
FIG. 189.



99. BUILDINGS FOR PUBLIC SPEAKING.—Distinctness of pronunciation is more useful, as a means of rendering public speakers audible, than all the assistance which art can give: and, by means of it, many persons are heard much more perfectly, and at a greater distance than others who possess far more excellent voices, but who pay little or no attention to this very important consideration.

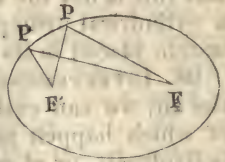
100. Anything which tends to prevent the voice from being dissipated in the upper parts of the building, must be advantageous to the speaker:—hence, *sound-boards* are placed over chairs, and pulpits. But these ought not to be such as to concentrate the sound in certain points: because it follows, from principles, to be explained when I shall speak of the foci of lenses and mirrors, that the more we strengthen sound, in these points, by reflection, the more we diminish its effect, in others. The parabolic sound-board seems to be the best; since the parabola has the property of reflecting all the rays of sound, which emerge from its focus F, fig. 190, in parallel lines, DP, EP—the angles of incidence and reflection being, then equal.

FIG. 190.



101. The shape of the building itself, is, undoubtedly, of importance. It is evident that the elliptic form will be the best, only when we desire that all the sound emitted from one focus F , fig. 191, should converge to F' , the other. —Lines drawn from the foci to P, P , any points of the curve, would represent the direction in which sounds, emitted in one focus would be reflected towards the other; since it is the property of the ellipse that these lines make equal angles with the curve, at P, P , &c. And, therefore, they will represent the equal angles of incidence and reflection, made by sounds proceeding from either focus, and reflected by the curve.

FIG. 191.



102. The nature of the walls and floor of a building, intended for public speaking is not to be neglected.—If the walls have many openings, the sound will be absorbed, very little being reflected among the audience; and, it is evident, that the voice will not be so effective in a room, &c., containing a number of recesses. If there are vaults, &c., under the floor, and the space between the latter and the arches is not filled with saw-dust, or some other substance, capable of intercepting the vibrations arising from the proximity of the hollow space, an effect highly injurious to the speaker will be produced. Some buildings are peculiarly favourable to the voice.—Yet their excellence is the consequence of causes, and conditions not easily discovered; and is seldom due, entirely, to the skill of the builders.

103. VENTRILOQUISM is the power of imitating an absent, a distant, or a different person:—it derives its name from the fact that those who possess it, sometimes seem to speak within their own stomachs.* This, however, was more true, anciently, than at present. Ventriloquism has often been perverted to the worst purposes; and is supposed to have been used in the ancient oracles. Its nature has given rise to much inquiry.—Perhaps the most correct opinion is, that it consists, merely, in an accurate perception of the difference of sound, consequent on difference of distance or of circumstances, and a facility of expressing this difference—which is acquired by a good ear, and much practice: and that it does not require any peculiar formation of the organs.

104. THE WIND is air in motion. It arises from various causes, which produce, in particular places, an increase or diminution in the bulk of the atmosphere. Among these are, the absorption of vapour during evaporation, or the loss of it by the production of rain; and the rarefaction of the air, due to an

* *Venter*, the stomach; and *loquor*, I speak. *Latin*.

increase in its temperature, which rendering it specifically lighter, causes it to ascend—when the heavier portions then flow in to supply its place. These circumstances produce winds of greater, or less duration; and atmospheric, like tidal currents [mech. 18], are modified by the different velocities of the air, according as the place whence it has come is more or less distant from the poles; &c.

105. The difference between the temperature of the land and sea, during the day and night, gives rise in hot countries, to *land* and *sea breezes*—the current being from the sea, in the evening, and from the land, in the morning. For, the temperature of the water being more uniform than that of the land, the former is colder by day, and warmer by night, than the latter; since, as fast as the surface of the water cools, at night, it is replaced by a warmer, because a lighter portion.

106. It is ascertained that there are different currents of air, at different heights from the earth:—indeed clouds, in a higher region, are sometimes driven by the wind in one direction; while those in a lower, are carried in the opposite.

107. ANEMOMETERS* are instruments, used for ascertaining the force of the wind. They are of various kinds:—in some of them, the wind is made to raise mercury, in a tube properly bent for the purpose; and they are, even, so constructed, as to record the force and direction of the wind, at the different periods of the day, and night. Sometimes water is employed instead of mercury.

108. Doctor Hutton gives the following results, water being used:—When the fluid was raised

Inches.	Lbs. to the sq. ft.	Miles per hour.
$\frac{1}{4}$ the force of the wind was	1.3; and its velocity	18
1 " "	5.2 "	36
4 " "	20.8 "	76
8 " "	41.7 "	101.6
12 " "	62.5 "	124

Since a cubic foot of water weighs 62.5 lbs. nearly, a square foot, one-fourth of an inch in height, weighs the forty-eighth part of 62.5 lbs., or 1.3 lbs.

109. The force of the wind [hyd. 69] is as the square of its velocity.—It travels at the rate of 100 miles per hour, and upward, only in great storms.

* *Anemos*, the wind; and *metreó*, I measure. Gr.

CHAPTER VI.

OPTICS.

Division of the Subject, 1.—Sources whence Light is derived, 2.—Nature of Light, 3.—**DIOPTRICS**. Refraction, 9.—Foci of Lenses, 27.—Images formed by Lenses, 35.—The Camera Obscura, 44.—Camera Lucida, 45.—Magic Lantern, 46.—*Microscopes*. The Single Microscope, 48.—The Compound Microscope, 53.—*Refracting Telescopes*. The Astronomical Telescope, 59.—**CATOPTRICS**, 65.—Foci of Mirrors, 67.—Images formed by Mirrors, 85.—The Reflecting Microscope, 95.—*Reflecting Telescopes*—The Gregorian, 96.—The Cassegrainian, 97.—The Newtonian, 98.—Spherical Aberration, 102.—**CHROMATICS**, 105.—Properties of the Spectrum, 116.—Photography, 120.—The Rainbow, 163.—Interference of Light, 170.—The Eye, 184. Long and Short Sight, 197.—**DOUBLE REFRACTION**, 205.—*Polarization of Light*, 210.—Interference of Polarized Light, 239.—Circular, &c., Polarization, 249.

1. **DIVISION OF THE SUBJECT**.—Optics* is a science, which treats of the nature of light, and of the laws, by which it is governed—but, principally of the latter. It was not unknown to the ancients:—Ptolemy wrote a treatise on it, which is lost.

It is divided into *Dioptrics*, *Catoptrics*, *Chromatics*, and *Double Refraction*—which includes *Polarization*.

2. **SOURCES WHENCE LIGHT IS DERIVED**.—Light is either natural—as that of the sun; or artificial—as that which is emitted by a lamp, &c. Putrescent substances, particularly fish and wood in a state of decomposition, emit light, which is not affected by a blast of atmospheric air, or oxygen: the light, however, from fish, is sometimes, and that from wood, is always, extinguished by nitrogen. The emission of this kind of light is prevented by hydrogen, carbonic acid, sulphuretted hydrogen, &c.

3. **NATURE OF LIGHT**.—There are two opinions on this subject: that of Newton—called the theory of “emission,” according to which, light is a very subtile matter, thrown out from luminous bodies; and that of Huyghens—called the “undulatory” theory, according to which, it is not a material substance, but the vibration of a highly elastic and very subtile fluid, as sound [pneum. 56] is the vibration of air. With regard to the more ancient opinions on this subject—for instance, that luminous bodies are perpetually throwing out *spectra* or images, &c., I pass them over in silence, as altogether absurd.

* *Opto*, whence; *optomai*, I see. *Gr.*

4. The undulatory theory is now almost universally adopted. —And it seems favourable to the opinion of universal space being pervaded by a very subtile fluid, that the observations made by Encke, on the comet bearing his name, indicate a retardation of that body, by such a fluid. Sir I. Newton has shown that this ethereal fluid, if it exist, is 700,000 times less dense than atmospheric air. In producing the various colours, it vibrates with amazing rapidity:—scarlet requires 458 millions of millions of vibrations, in a second; and violet, 727 millions of millions.

5. Light is emitted from a luminous body in all directions, and in straight lines. As these continually diverge, the space over which they are spread continually increases, and by consequence, the intensity of the light diminishes to the same extent:—that is, the intensity varies, inversely, as these spaces; and the latter are proportional to the squares of the distance. A luminous body will, therefore, give four times as much light, at the distance of one foot, as at the distance of two feet: and nine times as much, as at the distance of three feet.

6. When light is thrown upon anything, it is either absorbed, transmitted, or reflected; or more than one of these effects is produced—indeed some light is always absorbed. When the body is *opaque*, that is, incapable of transmitting light, there is formed behind it a shadow, which continually increases if the luminous body is less than the opaque, but continually diminishes if it is greater: in the latter case, when the luminous body is considerable, there is around the true shadow a half shadow which constantly increases, and is due to the light from some parts of the luminous—but not from others—being intercepted by the opaque body. Certain substances are *transparent*,* that is, allow an object to be distinguished through them—as glass, &c. Some are *translucent*,† that is, allow the passage of light, but, in so confused a mass, that nothing can be distinguished through them: such, for example, are paper, muffled glass, &c.

The smallest conceivable portion of light is termed a *ray*; and whatever affords a passage to light, is called a *medium*.

7. Light travels at the rate of 192,000 miles in a second. This is known, by the time it takes to pass across the earth's orbit—which is estimated by the additional time, required for an eclipse of a satellite of Jupiter to become visible, when the earth is at a part of its orbit farthest from that planet. Were light a material substance, its particles should be inconceivably minute; since, notwithstanding their enormous velocity, their momentum would be such as to cause no inconvenience to an

* *Trans*, through; and *appareo*, I appear. *Lat.*

† *Trans*, through; and *luceo*, I shine. *Lat.*

organ so delicate as the eye. Light travels from the sun to the earth, in about seven and a half minutes.

8. M. Arago remarks, that light from a self-luminous body may be distinguished from that which is reflected, by its continuing visible, at any distance—provided the luminous body remains of a sensible diameter. A body, seen by reflected light, may, on the contrary, vanish, while its diameter is still considerable. When light comes from a self-luminous body its brilliancy is inversely as the square of the distance [5]:—if, therefore, we look at a self-luminous body, through a small aperture, wherever the aperture may be situated, the brightness of the body will be still the same: for if, on the one hand, it is diminished as the square of distance is increased; on the other, it is augmented to the same extent, by a larger portion of the luminous body coming into view. Uranus is 19 times farther from the sun than our earth; hence, to an inhabitant of that planet, the sun appears like a star, the diameter of which is 100 seconds:—that is, it must have the same brilliancy, as if seen by us, through an aperture of 100 seconds. For the weak light of the whole disc, as seen at Uranus, is just equal to the strong light from a part of the disc, as seen by us through the aperture: and it will be visible, so long as it is of a sensible magnitude—just as we can see it through an aperture, so long as the latter is of a sensible magnitude. Since comets become dim before they cease to be of a sensible magnitude, it is to be inferred, that they do not shine by their own, but entirely or to a great extent by a reflected light.

9. DIOPTRICS.*—REFRACTION.—Under this head, are considered the laws which relate to *transmitted* light. When light passes from one medium to another, of greater, or less density, it is always *refracted*†—that is, turned out of the same right line: but, ordinarily speaking, not out of the same plane. The refraction of light may be illustrated by a very simple experiment.—If a stick is immersed in water, &c., however straight it is in reality, it will in appearance be broken, where it enters the fluid. Or, if a shilling A, fig. 192, is placed in a basin of water BD, when we stand in such a position that it will just be visible from R, over the edge, it will cease to be seen from the same point, should the water be removed:—because the path of the ray will change from ABR to ABR', since it will no longer be refracted. Euclid remarked the effect of refraction, illustrated by this experiment: but the ancients were better acquainted with catoptrics than with dioptrics. Since an object appears in water about one-fourth

FIG. 192.



* *Dia*, through; and *opto*, I see. *Gr.* † *Re*; and *frango*, I break. *Lat.*

higher than it really is, the depth of a river, &c., is greater than it appears.—Many accidents have happened on account of persons mistaking the depth of water, from this cause.

10. When a ray falls perpendicularly on the surface of a medium, there is no refraction. Since the sun is never in our zenith, it never seems to us to be in the place, in which it really is.

11. The constant relation between the sines of the angles of incidence and refraction is called the *ratio of the sines*, or the *index of refraction*.—Ptolemy, the astronomer, noticed the existence of some such relation. It has been ascertained for a number of substances: of which the most remarkable are the following.

We shall, for convenience, consider the angles of incidence, refraction, reflection, and polarization, as made by a ray with a *perpendicular* to the surface [mech. 136], and not with the surface itself.

	Index of Refraction.
Chromate of lead (highest refraction),	2.974
———— (least refraction),	2.500
Diamond,	2.439
Glass (lead, 3; flint, 1),	2.028
—— (lead, 2; sand, 1),	1.987
—— (lead, 2; flint, 1),	1.830
—— (lead, 1; flint, 1),	1.787
—— (lead, 3; flint, 4),	1.732
—— (lead, 1; flint, 2),	1.724
Mother of Pearl,	1.653
Flint glass, from 1.625 to	1.590
Bottle glass,	1.582
Rock salt,	1.557
Melted sugar,	1.554
Amber,	1.547
Plate glass, from 1.542, to	1.514
Crown glass, from 1.534, to	1.525
Oil of turpentine,	1.475
Alcohol,	1.372
Salt water,	1.343
Crystalline lens of the human eye,	1.384
Air (Biot), barom. 30.17, thermom. 32°,	1.0009295

Gases, according to Dulong.

	Index of Refraction.
Hydrogen,	0.470
Oxygen,	0.924
Atmospheric air,	1.900
Nitrogen,	1.020
Ammonia,	1.309
Sulphuretted hydrogen,	2.187
Sulphuret of carbon,	5.179
Sulphuric ether,	5.280

12. Although, with the same surface, the angles of incidence

and refraction have the same ratio, the refraction increases with the obliquity of the incidence.

13. We cannot rely on celestial observations, made within ten or twelve degrees of the horizon, on account of the density of the atmosphere being subject there to irregular variation. The quantity of refraction, at the same distance from the zenith, varies nearly as the height of the barometer, the temperature being constant. Every rise in temperature, equal to a degree Fahrenheit, diminishes refraction by about the $\frac{1}{480}$ th part. The refraction of the atmosphere is not affected by its hygrometric state. Dr. Bradley found by calculation, the amount of refraction corresponding to each altitude.* The twinkling of the stars arises from sudden changes in the refractive power of the air—which would be imperceptible, if they had discs, like the planets.

14. High refractive power indicates inflammability in the substance which possesses it. The knowledge of this law induced Sir I. Newton to foretel that the diamond would be found to be combustible—a prediction, since verified.

15. When a ray passes from a less to a more dense medium, it is turned *towards* a perpendicular to the surface of the medium; when from a more to a less dense medium, it is turned *from* a perpendicular to the surface.

16. The most transparent substances absorb some light, as it passes through them. The density of the stratum of air, at the horizon, causes it to diminish the sun's light, during transmission, 1,300 times.—Hence, we can look at the sun, when in the horizon, without being dazzled.

17. Bodies act on rays of light, before they come in contact with them :—hence shadows are larger than they ought otherwise to be ; and a knife-edge will turn light out of its path.

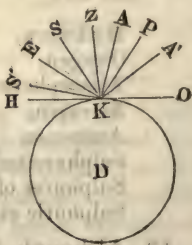
18. A *pencil* of rays, is a portion of light, distinct from the rest. Rays are either *parallel*, *converging*, or *diverging*.

19. The *focus*† is a point towards which rays converge ; it is *real*, when the rays actually meet ; *imaginary* or *virtual*, when, to make them meet, they must be produced. The word

* He used the following method.—Let K, fig. 193, be the position of a spectator on D, the earth. Let HO be the horizon; P the pole of the equinoctial E; A, the highest place of a star, very near P, and A' its lowest place; let S be the sun's greatest altitude, S' its least; and Z the zenith. A, on account of the earth's rotation, on its axis, will seem to revolve round P; then AZ will be the star's least, A'Z its greatest zenith distance; and, but for refraction, $AZ + A'Z = 2ZP$. Again, ZS is the sun's distance from the zenith at its least, and ZS', at its greatest altitude; and, but for refraction, $ZS + ZS' = 2ZE$. But $2ZP + 2ZE = 2ZO = 180^\circ$.—Therefore, but for four refractions, $AZ + A'Z + ZS + ZS' = 180^\circ$.

† *Focus*, a fireplace. *Eat*.

FIG. 193.

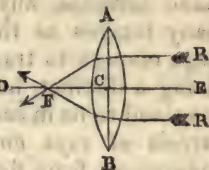


“focus” is very appropriate, since rays of light in sufficient quantity, when concentrated to a point, have the power of burning.

20. The *principal focus* is that of parallel rays—or the point to which the rays, entering the lens in a parallel direction, converge, after leaving it.

FIG. 194.

21. The *geometrical focus* is a point F, fig. 194, at which rays RR, supposed to be indefinitely near ED, the axis of the lens AB, intersect each other.

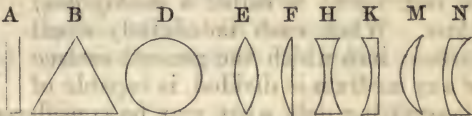


22. A *lens* is a “medium” having, at least, one surface convex, or concave.

23. The forms which media are most usually made to assume, for the purpose of refraction, are, the parallel plate A, fig. 195;

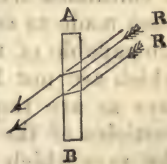
FIG. 195.

the triangular prism B; the sphere D; the double convex lens E—of which the convexities may be either equal or unequal; the plano-convex lens F; the double concave lens H—of which the concavities may be either equal, or unequal; the plano-concave lens K; the meniscus M; and the concavo-concave lens N.



24. *Refraction through a plane glass.*—Neither the parallelism, convergence, nor divergence of rays is altered, by transmitting them through a glass plate having parallel surfaces. But it changes the real, though it does not affect the relative position of objects RR, fig. 196.

FIG. 196.



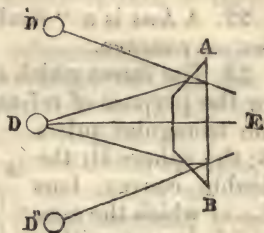
25. *Refraction through a prism.* The index of refraction for the substance of which a given prism is made being known, it is easy to find the paths of a ray DT, fig. 197, making an angle DEN with NQ, a perpendicular to the first surface RB.—For [11] we know the ratio of the sines of DEN, and FEQ, the angles of incidence and refraction, at the first surface; we know, also, TFH, the angle, made by the emerging ray, with a perpendicular to the second surface AR—for we know the ratio of the sines of EFP, and TFH, the angles of incidence and refraction at the second surface.

FIG. 197.



26. Since a single ray of light must be inconceivably small, when it touches a curved surface, it may be supposed to touch a tangent plane, coincident with that surface:—for any curved surface can, without sensible error, be considered as made up of an infinite number of plane surfaces. But, when the latter becomes of a sensible extent, their effect is greatly altered. Hence, if a curve surface is ground into a number of small plane surfaces, any object seen through it will produce as many images as there are surfaces: because each surface is large enough to transmit a separate parcel of rays—capable of giving a distinct, but not a magnified, image: and an object is imagined to be in each of the directions, from which the different parcels of rays come. This may be understood from fig. 198. AB is supposed to consist of three plane surfaces

FIG. 198.



—the number is of no consequence: each of them transmits distinct parcels of rays, and produces, therefore, a separate image of the object D. Such an instrument is called a *multiplying glass*. When each indefinitely small surface, into which the general surface of any medium is divided, is capable of transmitting only what may be considered as a single ray; it can, evidently, give to the mind no idea of any object; for, as the ray comes from but one point, there are many points, from which each of the indefinitely small surfaces transmits no rays. Hence, when glass is *muffed*—that is, rendered rough, though it continues *translucent*, it ceases to be *transparent*. It has been made to consist of a vast number of small surfaces, which are capable of turning the rays in all possible directions, but which are not large enough, individually, to transmit so many rays as are required to form the image of an object. The particles of the atmosphere, in this way, disperse on all sides, the rays which come from the sun, and fill the space around the earth with light. Without an atmosphere, that luminary would be a bright globe, suspended in a dark sky; and, while the sides of objects next to it, would be extremely bright, their other sides would be quite dark, and invisible.

Some of the effect of the atmosphere is due to reflection.

27. FOCI OF LENSES.—F, fig. 199, FIG. 199.

the principal focus of a sphere, which may be considered as a prism formed by planes tangential to its curve, at Q, and T, the points of contact with the rays RR, may be found by the means which [25] enabled us to trace the rays of light

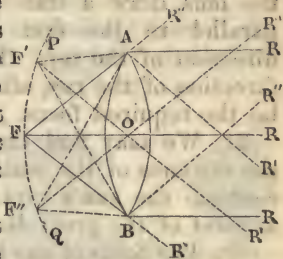


through a prism. For the path of R and R' , must be such, that the ratio of the sines of the angles of incidence and refraction, will be the index of refraction for the given substance; and the point F —where lines, making these angles with the perpendiculars HP , BE , &c., intersect each other, after leaving the sphere—will be its principal focus, since R and R' are supposed parallel.

28. All the principal foci $FF'F''$, &c., fig. 200, are nearly equi-

FIG. 200.

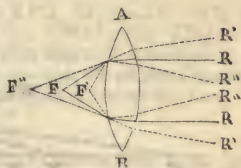
distant from O , the centre of the lens—or that point, at which, the part of the axis, intercepted between the surfaces of the lens, is bisected: hence the image of an object is curved. If the centre ray of the pencil is coincident with the axis RF , the focus will be F : if coincident with $R'F'$, it will be F' : if coincident with $R''F''$, it will be F'' . Should the centre ray commence at any of the intermediate points, the focus will be found in some point of the curve $F'FF''$ —which is not, however, exactly, the portion of a circle. Rays passing through the centre C may be considered to suffer no refraction; as the equal and opposite refractions do not alter their direction.



29. Convergent rays R/R' , fig. 201, will come to a focus F' , nearer to the lens than F , the principal focus. If they are

FIG. 201.

divergent, as R/R'' , their focus F'' is farther off than F . The *radiant point*, or that from which they emanate, and the focus, to which they are concentrated, are called *conjugate foci*, and are interchangeable. Their distances, from the principal focus, at the side of the lens respectively next them, vary, inversely:



because the more the incident ray diverges, that is, the more the radiant point approaches the principal focus, the farther the emergent ray will travel, before it can intersect a ray passing through the centre of the lens:—because the incident and emergent rays must make the same angle, as one of the parallel rays [27] makes with its corresponding emergent ray.

If the radiant point is at a distance from the lens, equal to twice its focal length, the focus of the rays, emanating from it, will be at the same distance, on the other side of the lens.

30. The focus of a lens may be found, practically, as follows:—Let the lens be either N , or N' , fig. 202; and let RB be the ray. Mark on a circle, described with a centre O , arcs which will measure the angles of incidence and refraction, at the first surface; and, on a circle, described with a centre Q , arcs which

will measure the angles of incidence and refraction at the second surface:—then trace the ray through the points taken in these circles: and, through the centre of the lens, draw a line parallel to the first direction of the ray. The point where this line intersects the direction of the ray, after, or before it has passed the lens, will be the required focus.

FIG. 202.

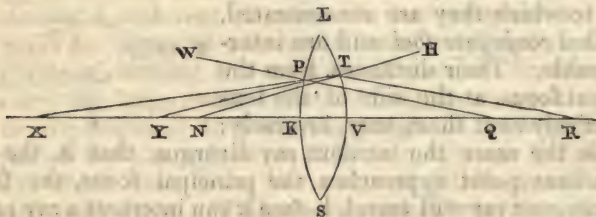


31. We may find the principal focus, also, by ascertaining the distance of the smallest point to which the lens will concentrate the sun's rays—which are considered as parallel, on account of the great distance of that luminary.

32. The focus of any kind of lens, for either parallel, converging, or diverging rays, may be ascertained by a general method, founded on principles given by Halley [Phil. Trans. 1693].*

* Let m , and n , be the sines of the angles of incidence, and refraction, when a ray passes from the atmosphere to a lens:—then $m:n$ will be [11] the ratio of the sines—or, of the angles themselves, as they are very small. Let LS, fig. 203, be a given lens; and let NT (=NV), be the radius of curvature of one of its surfaces. Produce NT to H. Let QP (=QK) be the radius of curvature of the other surface. Produce QP to W. Let R be any radiant point:—to find YK, the distance of the other conjugate focus from the lens. Let the point T,

FIG. 203.



be very near the axis; let RT, be a ray from R; and let the first refraction be, in the direction of TP. Produce TP to X.

In the triangle RTN, $RN:RT::\sin. RTN (= \sin. RTH, \text{ the angle of incidence, or } m) : \sin. TNR$. But, when angles are very small, they may be considered as proportional to their sines:—therefore $RN:RT::m:TNR$. But $RN = RV + VN$; and $RT = RV$ (because T is very near V)—Hence, substituting these, we have $RV + VN:RV::m:TNR = \frac{RV.m}{RV + VN}$.

But the angle $TXV = TNR - XTN = TNR - n$ (since XTN is the angle of refraction) = (their equals) $\frac{RV.m}{RV + VN} - n = \frac{RV.m - RVn - VN.n}{RV + VN}$.

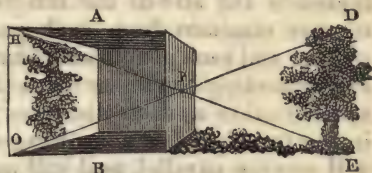
In the triangle NTX, $NT:XT (=XV; \text{ because T and V, are supposed very near})::\sin. TXY:\sin. TNX = \sin. TNR, \text{ its supplement;—or, (since they are very small) as the angles themselves; or, finally, as (their equals just found)}$

33. Since the conjugate foci are interchangeable, and it is immaterial from which extremity of it we consider the ray to begin its motion, rays will not come to a focus, with a lens, if the radiant point is at an equal, or less distance from the lens, than the principal focus.

34. *The burning glass* is merely a convex lens, which concentrates the rays to a focus—at which point the heat is increased in proportion as the space which the concentrated rays cover, is less than the surface of the lens.

35. IMAGES FORMED BY LENSES.—If a small aperture P, fig. 204, is made in a window shutter, &c., an inverted image of the object ED, will be thrown on

FIG. 204.



a wall HO, intended to receive it—the rays which would confuse the image being excluded. If a lens is placed in the aperture, it will render the image brighter, by collecting rays which must, otherwise have escaped. Aristotle remarked that, whatever the shape of such an aperture, the image of the sun, formed by it, is always circular:—but the fact, was not explained, until many

$$\frac{RV.m - RV.n - VN.n}{RV. + VN} : \frac{RV.m}{RV + VN} \text{ Therefore } XT \text{ (or its equal, } XV) = \frac{RV.m.NT}{RV + VN} \div \frac{RV.m.NT}{RV + VN} = (m-n)RV - VN.n$$

To find YK, put $XV - KV = d$. In the triangle XPQ, $XQ (= XK + KQ = d + PQ) : XP (=d; \text{ because } TV \text{ is very small}) :: \sin. XPQ (= \sin. TPQ) : \sin. PQX :: (\text{because the angles are very small}) XPQ \text{ (the angle of incidence } n : \text{ for, since the ray, in this case, passes from the lens to the air, the angle of incidence is less than that of refraction) : } PQX$.—And substituting equal quantities,

$$d + QP : d :: n : PQX = \frac{d.n}{d + QP}$$

In the triangle QPY, the angle $PYQ = WPY - PQX = m$ (the angle of refraction being now the greater) $- PQX = m - (\text{the equal of } PQX, \text{ just found})$

$$\frac{d.n}{d + QP} = \frac{(m-n)d + QP.m}{d + QP} \text{ And } QP : YP (=YK; \text{ because the point P, is very near K}) :: PYQ : PQX :: (\text{their equals, just found}) \frac{(m-n)d + QP.m}{d + QP} : \frac{d.n}{d + QP}$$

$$\text{Therefore } YP \text{ (or } YK, \text{ the distance of the focus from the lens)} = \frac{d.n.QP}{d + QP} \div \frac{(m-n)d + QP.m}{d + QP} = \frac{QP.d.n}{(m-n)d + QP.m}$$

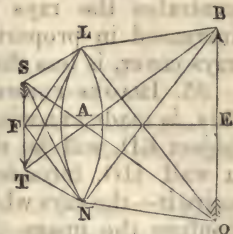
We may substitute, for d , its value $XV - KV = \frac{RV.m.NT}{(m-n)RV - VN.n} - KV$, and we shall have the focus of double convex lenses, for divergent rays. If the thickness of the lens is inconsiderable, it may be neglected. If the rays are converging, RV , will be negative; if the rays are parallel, it will be infinite. If either surface is concave, the radius of that surface will be negative; if both are concave, the radii of both will be negative. If either is a plane surface, the radius of that surface will be infinite.

If any one term of this equation is unknown, it can, of course be found.

centuries after. It is due to an infinite number of images, each the same shape as the aperture, being produced by all parts of the sun, and superimposed. These, when seen together, must—since the sun is circular—form a circular surface.

36. The use of a lens LN, fig. 205, in the aperture, cannot cause the image to be confused; since rays from the various parts of the object OB, cannot interfere with each other. The nearer the object to the focus of the lens, the larger will be the image ST; for the angle, under which it is seen is increased, which—as we shall see presently—increases the size of the image. Pencils of rays emanate from each point in the object; and each pencil is concentrated to a corresponding conjugate focus [29]. The image and object are to each other as their distances from the lens. If the object is in the principal focus, no image will be formed, since the rays will emerge parallel, and will not come to foci.

FIG. 205.



37. The farther the image is from the lens, the larger it is; because the more divergent the pencils become, before the rays of which they consist, come to their respective foci. If the image is farther from the lens than the object, it is larger than the object; and, *vice versa*. The nearer the object is to the principal focus, the larger its image; because the rays emerge more nearly parallel—and, consequently, are the longer without coming to foci. A single lens gives an inverted image.

38. The image, formed by a lens, may be thrown on a screen of linen, muffed glass, &c. Persons have been frightened by images, formed with the magic lantern, being thrown on a fog—which acted like a screen.

Rays will emerge from the image in a focus, as from a new object; and may, with reference to lenses, &c., be treated as such.

39. A lens seems to bring an object nearer, because it increases the angle under which it is seen—which would be effected, also, by bringing it nearer.

40. Fig. 206 shows how it is that the size of an image is increased, on account of the angle PNQ, which the object PQ = AB, subtends, being greater than the angle ANB, on account of PQ being nearer than AB to the lens N—supposed to be the crystalline humour of the eye. RS, the image formed by PQ, is larger than TV, which is formed by AB: and the image TV will

FIG. 206.



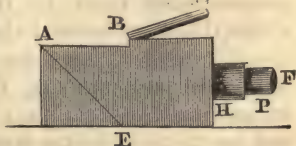
evidently be produced, not only by AB, but also by the smaller objects DE and HO. We may intercept the view of the largest landscape, with a sixpence, if we bring the latter sufficiently near:—since we may cause the image of the sixpence, within the eye, to be larger than that of the landscape. Increasing the angle of vision ANR, increases the image in the eye; because the pencils of rays, from the object, become more divergent, before they come to foci within the eye. The apparent size of the object is inversely proportional to its distance from the eye.

41. The apparent size of an object is magnified when, instead of the object itself, we view the image formed by a lens. For, if the object is 5,000 feet distant, and we use a lens of five feet focal length, the image will be to the object::5:5,000 [36]:—that is, it will be 1,000 times smaller. But, since this image may be considered as a new object [38] and may be viewed by the eye, not at the original distance of 5,000 feet, but at that of six inches, the smallest distance at which we can obtain distinct vision, the angle under which it is seen is greater; and [40] the image is as much larger, when seen at the distance of six inches, than when seen at the distance of 5,000 feet, as 5,000 feet is greater than six inches. The image, therefore, is, from this cause, magnified 10,000 times; and, since it was 1,000 times less than the object, it is equal to the object divided by 1,000, and, multiplied by 10,000; and, consequently, it appears ten times as large as the object. If the length of the object is increased ten times, its entire surface is increased $10^2=100$ times.

42. When the distance of the object is very great, compared with the focal length of the lens, the magnifying power is equal to that length, divided by six inches, the smallest distance of distinct vision.

43. A lens, besides magnifying an object, increases its brightness, by intercepting rays which would otherwise escape. If this were not the case, the image would be as much less bright than the object, as its size is greater—the same number of rays being diffused over a larger surface.

44. THE CAMERA OBSCURA,* invented by John Baptista Porta, is a box, or chamber AEH, fig. 207, of any size. F is a lens, fixed opposite to the mirror AE—forming an angle of 45° with the horizon. The rays, from external objects, are transmitted by the lens; and being reflected by the mirror, are received on the surface AB—supposed, in the present instance, to be muffed glass.

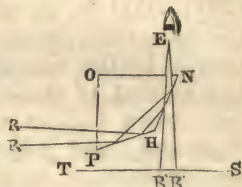


* Dark chamber. Lat.

This surface ought, strictly speaking, to be curved [28], that the foci corresponding to the different parts of the object may coincide with it: but a somewhat different arrangement would then be required. The construction of the Camera Obscura, is only a development of the principle, which causes a picture of external objects to be produced on the opposite wall, by an aperture in the window-shutter, &c. [35.] This instrument assumes a variety of forms; it is, sometimes, a chamber sufficiently large to contain several persons.

45. THE CAMERA LUCIDA,* was invented by Dr. Wollaston. It depends on the fact, that the object is always referred by a spectator, to the place whence, on account of their *last* direction, the rays appear to have come.—A landscape, &c., may seem to be a picture, placed on a

FIG. 208.



sheet of paper, &c., provided the last direction of the rays, by which it is seen, is from the paper, &c. to the eye of the observer. This is effected by a quadrangular prism of glass ONHP, fig. 208, of which the angle at O is 90° ; that at N 67.5° ; that at H 135° ; and that at P 67.5° . Rays RR, from some object will, after falling on PH, be reflected by the interior surface HN to an eye at E; and, on account of their last direction, will seem to come from an object R'R' on the paper, &c., TS. If a perforated piece of metal is placed upon ON, so that only half of the aperture is over the angle N, both image and paper—apparently coincident—will be visible to an eye placed over the aperture: and the outlines of the object may be sketched, with great accuracy, by a pencil, &c.

FIG. 209.



46. THE MAGIC LANTERN consists of a box, fig. 209, on the bottom of which is placed a lamp L, capable of sliding either towards OP, or in the opposite direction. A plano-convex lens, Q, fixed in the front, throws the rays, in a concentrated form, on the glass slide OP—represented also by AB—containing figures, &c., drawn with transparent paint. The rays, in passing through the slide, are coloured; and, being transmitted through a powerful lens MN,

* Lighted chamber. *Lat.*

are thrown on a screen which is in one of the conjugate foci, the slide being in the other. If the objects on the slides are alone visible, being surrounded by portions of the glass that have been rendered perfectly opaque, when the room is darkened, they will seem to a spectator placed behind the screen, like phantoms in the air:—such representations are, on this account, sometimes, called *phantasmagoria*.* The distance of the image, and therefore [37] its size, is altered by moving the lens MN, which, for this purpose, is made to slide in a tube attached to the lantern. The magnitude of the image is, however, limited by the illuminating power of the lamp, which is increased by the concave reflector F.

FIG. 210.

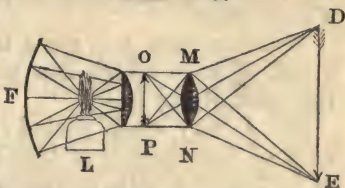


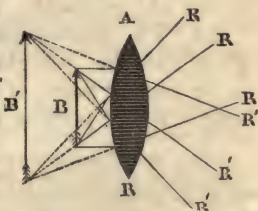
Fig. 210 represents the manner in which the rays form the image on the screen DE.—The letters correspond with those in fig. 209. Other combinations of lenses, also, are used.

47. *Dissolving views* are produced, by two magic lanterns, fixed at the same focus, and so arranged that the light in each may be almost extinguished, at pleasure. When the picture is to be changed, the light of one lantern is brought, by degrees, almost to nothing, while that of the other is, in the same manner, increased to a maximum:—by this means, one view fades away, and the other *gradually* becomes perfectly distinct.

48. MICROSCOPES.—THE SINGLE MICROSCOPE.†—Microscopes are instruments which, by giving an enlarged image of a minute object, enable us to see it more perfectly. They are either single, or compound.

The *single*, termed also the *simple microscope*, consists, merely of a lens AR, fig. 211. When an object is placed in the principal focus, the rays will emerge parallel; when at B, a little nearer to the lens, they will emerge with the same amount of divergence as if the object were placed at B', the distance of distinct vision; and, on account of the visual angle being increased, it will appear as large as B', instead of B—its apparent size, if it were at B'.

FIG. 211.



49. If the visual angle were increased, without a lens being used, the rays would enter the eye in such a state of divergence, that the power of adaptation possessed by that organ, would not be capable of bringing them to foci, on the mem-

* *Phantasma*, a phantom; and *ago*, I bring. Gr.

† *Mikros*, small; and *skoepo*, and I examine narrowly. Gr.

brane intended to receive the image. But, when the lens is interposed, the divergence of the rays is precisely what it would be, if the object were at the distance proper for distinct vision.

50. The magnifying power of a single microscope, is found, by "dividing the distance of distinct vision, by the focal length of the lens."*

EXAMPLE.—The focal length of a single microscope is $1\frac{1}{2}$ inches:—what is its magnifying power?

The distance of distinct vision being six inches, $\frac{6}{1.5} = 4$, the required magnifying power. The *surface* will be magnified $4^2 = 16$ times.

Watchmakers, &c., use a lens, of about one inch focus, set in a cell of horn which can be grasped by the muscles around the orbit of the eye.

51. A very small globule of glass—formed by melting the ends of fine threads of that substance in the flame of a candle, or by taking a little powdered glass on the point of a very small needle and melting it into a globule—will be found a powerful simple microscope. Such were the instruments, with which Lewenhoeck made all his discoveries.

52. Single microscopes do not, necessarily, consist of a single lens:—there may be any number, provided that, taken together, they produce the effect of only one. Two lenses form what is called a *doublet*; three, a *triplet*:—so many as seven have been used.

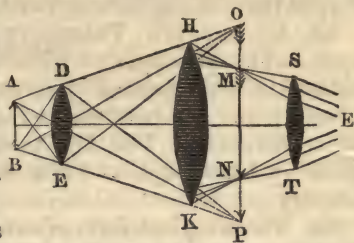
53. THE COMPOUND MICROSCOPE differs from the single, in having the image, formed by one lens called the *object-glass*, magnified by another termed the *eye-glass*. It is not necessary, however, that there should be but two lenses:—there may be any number, provided the effect of but two is produced. The eye-glass acts, with reference to the image formed by the object-glass, in the same way as the single microscope, with reference to the object itself.

54. The *field-glass* is a lens, interposed between the object-glass and the eye-glass, to increase the "field of view:" that is, to render more of the object visible, at once. Without it, only a small portion of AB, fig. 212, could be seen, unless by

* For, as the apparent size of the object is inversely proportioned to its distance from the eye [40], its apparent size at B', fig. 21, is to its apparent size at B, as its distance from the centre of the lens in the latter case (which may be called d) is to its distance, in the former, (which may be called d').—Therefore, its apparent size at B', equal its apparent size at B $\times \frac{d'}{d}$. But d' , is the distance of distinct vision: and d , is the focal distance. The point where the axis of the pencils from the object intersect each other, is supposed to be the *centre* of the lens:—which is not the case; since it is in the eye, behind the lens. The latter is, however, so near the eye, and its thickness is so small, that the error is inconsiderable.

changing its position, and bringing different parts of it, successively, into view. For, the rays, from its extremities, would, after passing through the object-glass, DE, diverge to O and P, so that they could not pass through the eye-glass ST—nor, by consequence, ever reach the eye. But, being deflected by the field-glass HK, they come to foci, at M and N, and after passing through ST enter the eye.

FIG. 212.



55. The magnifying power of a compound microscope is found, “by multiplying together the magnifying powers of the object and eye glasses.” Thus, if an image produced by the object-glass is six times greater than the object, and this image is magnified ten times by the eye-glass—because seen at one-tenth of the distance of distinct vision [50], the microscope increases the apparent size of any dimension of the object sixty times.

56. *The oxy-hydrogen microscope.*—It has been already remarked [43] that, when the apparent size of any thing is increased, the quantity of light must be augmented to, at least, an equal extent. This object was frequently obtained, by causing the rays of the sun to pass through whatever was to be examined. But such a mode of illumination was attended with several inconveniences:—among others, a cloudless sky cannot always be had; and the sun’s apparent motion renders it necessary that the mirror which throws the light on what is being magnified, should have its position continually changed. The great brilliancy of the oxy-hydrogen lime-light soon suggested it as a substitute for the solar rays; and the oxy-hydrogen microscope has almost entirely superseded the solar.

57. The magic lantern and oxy-hydrogen microscope are very similar in principle, but the objects used are different; as, also, the size, and number of lenses, &c.

58. In consequence of their high refractive power, lenses formed of the diamond, and other precious stones, have been used in microscopes. A diamond lens, having the same magnifying power as one of glass, requires to be only one-third as thick. The diamond lens may, therefore, be made of greater diameter:—this allows a greater quantity of light to enter the eye. However, the property of double refraction—which, as we shall see, produces a double image—the colour, and the heterogeneous structure of precious stones, have been found to more than counterbalance the advantages obtained from them,

The attempt to employ fluid lenses; or to give glass other shapes than the spherical, have been equally unsuccessful.

59. REFRACTING TELESCOPES.—THE ASTRONOMICAL TELESCOPE.—The principle on which the telescope depends,* is said to have been discovered by an accident, which has been variously related; and the result of which, at the time it happened, was not understood. The first telescope is supposed to have been made by John Baptista Porta, towards the end of the sixteenth century.

60. The simplest form of astronomical telescope consists of a double convex lens, placed at one end of a tube, six inches longer than the focal length of the lens.—An image is formed, in the air, within the tube, six inches from the end where the eye is placed: and is seen as a new object [38].

61. The effect of such an instrument is easily found, from what has been already said [41]. Its power is still farther increased, by placing, at the extremity of the tube, next the eye, a lens QR, fig. 213, the focus of which coincides with the focus of the object-glass.

FIG. 213.

This eye-glass increases the apparent size of the object AB, by magnifying the



image FH, produced by the object-glass DE. It is evident that there is a close resemblance between this telescope, and the compound microscope:—the chief difference between them being, that the image produced by the object-glass of the microscope is larger, while that produced by the object-glass of the telescope is smaller than the object—since it is formed [36] at a much less distance from the object-glass, than the place occupied by the object.

62. The magnifying power of this telescope is obtained, by dividing the focal length of the object-glass, by the focal length of the eye-glass.†

* *Tēle*, afar off; and *skopeo*, I observe narrowly. *Gr.*

† For, calling the centre of the object-glass DE, fig. 213, C; the centre of the eye-glass QR, V; and the central point of FH, N: the angle, under which the object AB would be seen, by a naked eye, if placed at C, is $ACB = FCH$. But the angle, under which the image is seen, is FVH . And, since [40] the apparent size of the same object, is inversely as its distance from the eye, $FVH:FCH::CN:NV$. Therefore, $FVH = \frac{FCH \times CN}{NV}$:—that is, any dimension of the object as seen, with the telescope, is equal the same dimension, as seen with the naked eye, multiplied by $\frac{CN}{NV}$. Therefore, $\frac{CN}{NV}$ is the magnifying power of the telescope. —But CN is the focal length of the object-glass: and NV, that of the eye-glass. The sum of both is the length of the telescope.

EXAMPLE.—The focal length of the object-glass is 3 feet ; and that of the eye-glass 1·04 inches ; what is the magnifying power? $\frac{3 \text{ feet}}{1·04 \text{ inches.}} = 34·61$ nearly.

63. Another lens is added, to render the image erect—and thus accommodate this telescope to terrestrial objects ; also, one to make the rays parallel, as they enter the eye—for that organ always sees distinctly, when the rays which enter it are parallel. These glasses, however, do not affect the magnifying power of the instrument. Although the rays, belonging to the pencils from the different parts of the object, or image, emerge parallel, the divergence of the axes of these pencils—or the visual angle—is not affected.

64. The different distances of objects require corresponding alterations of the focus of the object-glass [29].—When, therefore, the object is nearer, the eye-tube must be drawn out : and when farther, pushed in. Dr. Brewster applied this fact to the measurement of distances :—the sliding tube of the telescope being graduated for the purpose. “The distance of the object minus the principal focus of the object-glass is equal to the square of the focus of the object-glass, divided by the increase of the length of its focus.”*

EXAMPLE.—The focus of an object-glass is 3 feet ; and the increase of its focal length is 0·00902 of a foot. The distance of the object, therefore, is $\frac{3^2}{0·00902} + 3 = \frac{9}{0·00902} + 3 = 997\frac{1}{2} + 3 = 1,000\frac{1}{2}$ feet.

65. CATOPTICS† comprehends the laws, &c., which govern *reflected* light. When light is refracted, some of it is lost by reflection. The mirrors which are used to reflect light, are either *plane*, *concave*, or *convex*; and they consist of glass covered with an amalgam of mercury, or of metal. When the mirror is of glass, most of the rays are reflected from the silvering, after being refracted by the glass. When light falls very obliquely, it is better reflected by glass, than by metal. The *plane of reflection* is a plane passing through the incident and reflected rays.

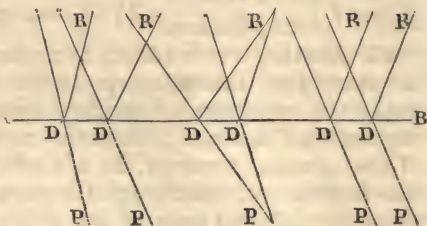
66. If parallel, converging, or diverging rays R, R, &c., fig. 214,

* Let F, be the distance of a focus from the principal focus—and also that of the conjugate foci [29], when they are equidistant. Let d be any other distance from the principal focus ; and let a be the distance of the corresponding conjugate focus. Since [29] the distances of the conjugate foci from the principal focus are inversely proportional, $F:d::a:F$ —and $d = \frac{F^2}{a}$. The whole distance of the radiant point, from the lens is $\frac{F^2}{a} +$ the distance of the principal focus.

† *Kata*, against ; and *opto*, I see. *Gr*.

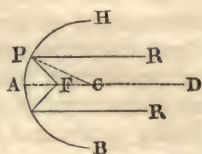
are thrown on a plane mirror AB, they will be reflected, at the points D, D, &c., and will seem to come from points P, P, &c., behind the mirror. Neither their parallelism, nor the angle of their convergence, or divergence, will be altered by reflection:—otherwise, as is evident from the figure, the angles of incidence and reflection would not be equal.

FIG. 214.



67. FOCI OF MIRRORS.—A concave spherical mirror, HAB, fig. 215, will reflect rays RR—supposed parallel to, and almost coincident with, AD the axis of HAB—to a focus, which will be at a distance from the mirror, very nearly equal to half its radius of curvature.*

FIG. 215.



68. The farther the rays are from DA the nearer their focus to the mirror:†—those which are very near are called *central rays*. If the axis of the mirror is turned towards the sun, the focus to which its rays are concentrated, may be considered as the principal focus—since, on account of the distance of that luminary, its rays may be looked upon as parallel. And we may ascertain the radius of curvature of the mirror by doubling its distance from the principal focus, thus found.

69. The focus of *convergent* rays will evidently be nearer to the mirror than the principal focus: and its distance from the latter will be equal to “the square of the radius of curvature, divided by the distance of the point of convergence from the principal focus.”‡

70. The distances of the conjugate foci from the principal focus vary inversely. Thus, if the distance of P' from F is

* For, C being the centre of curvature, draw CP. The radius is perpendicular to the curve at the point of contact; and, since the angles of incidence and reflection are equal $\angle CPR = \angle CPF$. But, since DA and RP are parallel, $\angle CPR = \angle PCF$:—hence $\angle CPF = \angle PCF$; and $FC = FP$ (because opposite to the equal angles). But, when RP is very near DA, FP (and, therefore, FC) may be considered $= FA$: and, when $FA = FC$, $FA = \frac{CA}{2} = \frac{\text{Radius}}{2}$.

† It is evident that, as the distance between DA, and RP, fig. 215, increases, the point F moves nearer to the mirror.

‡ Let C, fig. 216, be the centre of curvature of the concave mirror TH. Let RD be very near and parallel to the ray, coincident with the axis RP': and let F be the principal focus. Let the rays be R'D and R'N:—P'' is their point of convergence: and F'', is their focus. The triangles P''DF and DF''F are similar, since they have a common angle at F; and the angles DP''F and FDF'' are

doubled, the distance of F'' from F will be diminished to one-half, &c.*

71. When the rays become parallel, P'' becomes infinitely distant: and, the divisor FP'' having become infinitely great, the quotient—that is, the distance FF'' —will become 0; F and F'' will then coincide.

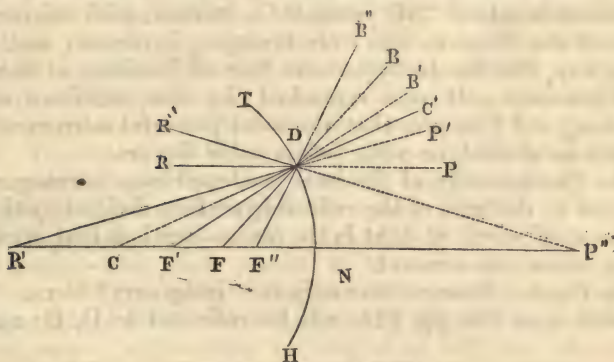
72. Since the path of a ray is the same, from whichever extremity of the line representing it we suppose it to begin its motion [33], when the luminous point is at F'' , the other conjugate focus will be at P'' , and *imaginary*.

73. The focus of *divergent* rays will be farther from the mirror than F , the principal focus: and its distance from the latter will be equal to “the square of half the radius of curvature, divided by the distance of the point of divergence from the principal focus.”†

74. The distances of the conjugate foci from the principal

equal, being each of them equal to $R'DR$.—For $DP''F = R'DR$, because RD and $R'P''$ are parallel; $FDF'' = R'DR$ because, since $R'DC$ (the angle of incidence) =

FIG. 216.



CDF'' (the angle of reflection), and $R'DC$ (the angle of incidence) = CDF' (the angle of reflection), $R'DC - R'DF = CDF'' - CDF'$ (FDF''). Hence $FP'' : FD :: FD : FF''$.

But, since RD is supposed very near $R'P''$, FD [67: note] may be considered = $FN = \frac{\text{Radius}}{2}$. Therefore $FP'' : \frac{\text{Rad.}}{2} :: \frac{\text{Rad.}}{2} : FF'' = \frac{\text{Rad.}^2}{2} \div FP''$.

* Since [69: note], $FF'' = \frac{\text{Rad.}^2}{2} \div FP''$, as $\frac{\text{Rad.}^2}{2}$ is constant, with a given mirror, FF'' varies inversely as FP'' .

† Let the rays be $R'D, R'N$, fig. 216:— R' is their point of divergence: and F is their focus. The triangles $R'DF$ and $F'DF'$ are similar:—since they have a common angle at F : and the angles $DR'F$ and $F'DF'$ are equal, being each of them equal to RDR' .—For $DR'F = R'DR$, because RD and $R'P''$ are parallel; $F'DF' = RDR'$ because, since $R'DC$ (the angle of incidence) = CDF' (the

focus, in this case also, vary inversely.* When the luminous point is in C, the centre of curvature, the focus, to which the rays converge will be at C, twice the focal distance, from the mirror [see 29].†

75. Since the path of a ray is the same, from whichever extremity of the line representing it, we suppose it to have begun to move [33], if the luminous point is in either of the conjugate foci, the rays will come to a focus in the other.

76. Concave mirrors are sometimes used to bring the sun's rays to a focus; and thus, to produce the same effect as the burning glass [34]. Some of the mirrors, employed for this purpose, have been very powerful:—that of M. De Vilette was 3 feet 11 inches in diameter, and its focal distance was 3 feet 2 inches; it was formed of tin and copper. A silver sixpence, placed in its focus, melted in $7\frac{1}{2}$ seconds; and a copper half-penny, in 16 seconds.

77. Burning mirrors are sometimes made with a number of plane mirrors, arranged so as to form a kind of curved surface. Count Buffon constructed one of 168 small mirrors, each 6 inches square; and, by means of it, with the feeble rays of the sun, in the month of March, set fire to beech-wood at the distance of 150 feet; and fused silver, at the distance of 50 feet. Archimedes, about 200 years B.C., burned, with mirrors, the ships of the Romans, who were besieging Syracuse: and, in the same way, Proclus destroyed the fleet of Vitellius, at the siege of Byzantium.—It was remarked by the members of the Academy del Cimento, that the most powerful mirrors will not set fire to alcohol, or other inflammable liquors.

78. The intensity of the heat produced by a burning mirror, is equal to the area of the reflecting surface divided by the area of the small circle of light in the focus—any loss that occurs not being taken into account.

79. *Convex Mirrors* have only an “imaginary” focus. Thus, parallel rays RR, fig. 217, will be reflected to D, D: and will

angle of reflection), and $R'DC$ (the angle of incidence) = CDF' (the angle of reflection), $RDC - R'DC$ (RDR') = $CDF - CDF'$ ($F'DF$). Hence

$$R'F:FD::FD:FF'.$$

$$\text{But } FD \text{ [69: note]} = \frac{CN}{2} = \frac{\text{Radius}}{2}.$$

$$\text{Therefore } RF: \frac{\text{Rad.}}{2} :: \frac{\text{Rad.}}{2} : FF' = \frac{\text{Rad.}}{2} \Big| \div RF.$$

* Since [73: note], $FF' = \frac{\text{Rad.}}{2} \Big| \div RF$, as $\frac{\text{Rad.}}{2} \Big|$ is constant, with a given mirror, FF' varies inversely as RF .

† For, since, in this case, RF , fig. 216, = $\frac{\text{Radius}}{2}$, the value of FF' [73, note] will become $\frac{\text{Rad.}}{2} \Big| \div \frac{\text{Rad.}}{2} = \frac{\text{Rad.}}{2} \times \frac{\text{Rad.}}{2} \div \frac{\text{Rad.}}{2} = \frac{\text{Rad.}}{2} = CF$.—The latter will, therefore, be the distance of F' from F ; and, consequently, F' will be at C .

seem to come from F, which would be the focus of parallel rays R'R', if the mirror were concave.

80. Parallel rays being represented by the lines PD, and P''N, fig. 216, and the convex mirror by TH, PD will be reflected to B and P''N back to P': and, if produced, they will intersect each other behind the mirror at F—the principal focus of parallel rays, when the mirror is concave. F, therefore, is a *real* focus, when the mirror is concave; but *imaginary*, when it is convex.

81. If converging rays are represented by the lines P'D and P''N, fig. 216, they will be reflected, respectively, to B' and P''; and the lines of reflection would, if produced, intersect each other at F'—the focus of diverging rays, the mirror being concave. F', therefore, is a *real* focus, when the mirror is concave: but an *imaginary*, when it is convex. If the convergence of the rays, or the curvature of the mirror were diminished, the focus might be more distant, or the reflected rays might become parallel—so as never to meet and produce even an imaginary focus.

82. If diverging rays are represented by P'D and P''N, fig. 216, they will be reflected, respectively, to B'' and P'': and, if the lines of reflection are produced, they will intersect each other at F''—the focus of converging rays, if the mirror were concave. F'', therefore, is an *imaginary* focus, when the mirror is convex, but a *real*, when it is concave.

83. The manner of determining the position of these foci, or of others, corresponding to rays having any given direction, may easily be found from what has been said [69, &c.]

84. When the surface, on which rays of light fall, is convex, it is evident that each portion of the surface, oblique to the luminous body, receives fewer rays than an equal portion, directly opposite to it. And the quantity diminishes, as a tangent to the surface approaches to parallelism with the direction of the rays.—This is one reason why, although the earth is nearer to the sun in winter than in summer, the light and heat it receives in the former, is less than what it receives in the latter season.

85. IMAGES FORMED BY MIRRORS.—A *plane* mirror AB, fig. 218, causes the object DH to appear at a side of the mirror different from that at which it really is. For, when the rays enter the eye, they seem to come from an object OP, at the other side of AB: and, therefore, [45] they are referred to OP. When a person views himself in a looking-glass AB, whatever his distance from the latter, the size of his image, on the glass, will always be found equal to half his real size.—For HT, the

FIG. 217.

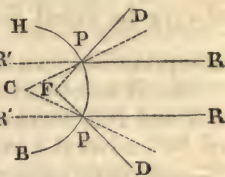


FIG. 218.



section of the rays proceeding from his image to his eye, will always be equal to $\frac{OP}{2}$ or $\frac{DH}{2}$: since the object and image are at equal distances from AB.

86. If an object AB, fig. 219, is placed between two mirrors, AN and NZ, inclined to one another at an angle of 60° , several images will appear, arranged in the circumference of a circle.—For the image of AB, in AN, is AP; and its image, in NZ, is DE; the image of AP, in NZ, will be ES; the image of DE, in AN, will be TO: OH is the image of TO, in NZ, and also of ES in AN—but these two images will not coincide, if the angle ANZ is more or less than 60° .

FIG. 219.



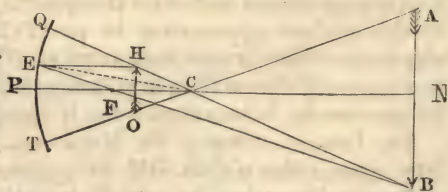
87. The *Kaleidoscope** is an instrument, founded on this multiplication of images, by mirrors forming an angle. It was invented by Dr. Brewster, and was proposed by him as a means of creating beautiful forms. The mirrors are to be placed at any angle which is an aliquot part of 360° . They are generally fixed in a tube, at one end of which are fragments of coloured glass, &c., lying between two parallel plates of colourless glass:—the surfaces of the latter are perpendicular to the line of intersection of the mirrors: and the outer one is muffled, to render the light uniform. On looking down the tube, through a small aperture, near the meeting of the mirrors and at the extremity opposite to that where the coloured glass, &c., is placed, a beautiful symmetrical figure will be seen, which will be varied every time the position of the coloured glass is changed, by slightly shaking the kaleidoscope.

This instrument has been made to produce combinations of flowers, trees, &c., by forming inside of it, with a lens, images of distant objects.

88. When the mirror QT, fig. 220, is

FIG. 220.

concave, an object HO, lying between C, the centre of curvature, and F, the principal focus, will form an inverted and enlarged image AB. For, Let



HQ, and HE be rays coming from H, some point in the object—the former in the same direction as the radius CQ. Let the angles HEC and BEC be equal. HQ, since it falls perpendicularly on the curve, will be reflected along QB; HE, will be reflected along EB, and will intersect QB, in some point B:—thus, rays from H will form an image of that point, at B. In

* *Kalos*, beautiful; *eidōs*, appearance; and *skopecō*, I observe narrowly. Gr.

the same way, an image of O will be formed at A; and images of each point in HO, at corresponding points of AB.

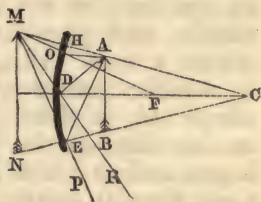
89. If AB is an object placed beyond C, the centre of curvature, an inverted and diminished image HO, will be formed between C and the principal focus.—Because, if the luminous point is in either conjugate focus, the rays emanating from it will [75] converge to the other.

90. The relative positions of the image and object may be determined from what has been already said [73].—Their relative sizes will be as the squares [41] of their distances from the centre of the mirror.*

91. A person standing in front of a concave mirror, and a little farther from it than its centre, will see an inverted image of himself in the air, which will advance, recede, stretch out the hand, &c., according to his own movements.—A large concave mirror, concealed from view, has been used in public exhibitions to produce singular deceptions. A person standing on his head in one conjugate focus, was seen by the spectators erect in the air, at the other. When any one attempted to take fruit, &c., from the hand of the image—which appeared a real person—a dagger was suddenly and dexterously presented in its place. The image, formed by a concave mirror, may be thrown on a screen, on the smoke from a chafing dish placed underneath, &c.

92. When the object AB, fig. 221, is between the *concave* mirror HE and its principal focus F, the rays appear to come from an erect and magnified image, behind the mirror. For, let AH, fig. 221, be a ray from A perpendicular to the mirror: it will be reflected back in the direction HC. Let AO be a ray parallel to the axis CD: it will be reflected [67] to F, the principal focus. If HC and OF are produced backwards, they will intersect each other at M—as will all rays DR, EP, &c., coming from A:—they will, therefore, be referred to M. In the same way those coming from B, will be referred to N; and those, from every other point of AB, to corresponding points of MN. They will, therefore, be referred to an enlarged image MN, behind the mirror HE.

FIG. 221.



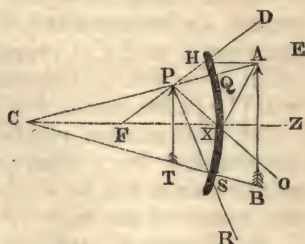
93. The nearer the object is to the mirror, the less the image:—when the object touches the mirror, its image is equal to it, in size. The latter may be easily determined.

94. If the mirror HS, fig. 222 is *convex*, rays from an object AB will seem to come from a diminished and erect image, behind it. Let AQ be a ray perpendicular to the curve HS;

* For Z, being a point, intermediate between H and O, $AB:HO::NC:CZ$. But their surfaces [41] are as $AB^2:HO^2$:—that is, as $NC^2:CZ^2$.

it will be reflected back in the direction QA. Let AH be a ray parallel to the axis CX, F being the principal focus, it will be reflected in the direction HD [79].

FIG. 222.



If QA and HD are produced backwards, they will intersect each other at the point P—as will all rays XO, SR, &c., coming from A:—they will, therefore, be referred to that point. In the same way, the rays coming from B will be referred to T; and the rays from all the points between A and B, to corresponding points in PT. They will, by consequence, seem to come from an image PT, behind HS.

The relative positions of AB and PT may be determined from what has been already said [69]. And their relative sizes are as the squares [41] of their distances from C, the centre of the mirror.

95. THE REFLECTING MICROSCOPE.—If HO, fig. 220, is a very small object, an image of it will be formed at AB, which may be viewed with the naked eye—or, what is better, with a convex lens. Such an arrangement would constitute a “reflecting microscope.”

96. REFLECTING TELESCOPES.—THE GREGORIAN TELESCOPE consists of a large concave mirror EF, fig. 223, containing an aperture in the middle, and placed within a tube AZ.

FIG. 223.

A smaller concave mirror D, is fixed in the axis of the larger, and at a distance from it, equal



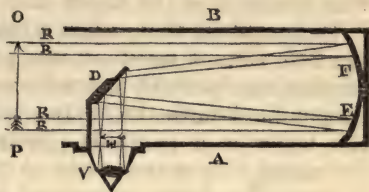
to a little more than the sum of their focal lengths. The smaller tube T contains the field glass B—which is a plano-convex lens, and the eye lens T. An image of the distant object OP is formed a little farther [73] from EF than its principal focus.—When this image is in the principal focus of D, the rays from it will be reflected parallel [72]. But, when it is a little farther from D than its principal focus, they will cross each other, and passing through the aperture in the larger mirror, will form a direct image at Q. Without the field glass S, which brings the rays more quickly to a focus, this image would have been at a greater distance from D, and many of the rays [54] would never have reached the eye. The image is magnified by the lens T.

A screw M is so arranged that, by means of it, the smaller mirror is moved along the axis of the larger—to accommodate the instrument to objects at different distances [74].

97. THE CASSEGRAINIAN TELESCOPE has a small convex, instead of concave mirror, at D, fig. 223 : it is placed at a distance from the larger mirror, equal to the difference of their focal lengths. In this telescope, only one image is formed—that at the eye-glass.

98. THE NEWTONIAN TELESCOPE consists of a large concave mirror, EF, fig. 224, fixed in a tube AB : of a plane speculum D inclined to the axis of the tube at an angle of 45° : and of a tube, containing an eye-piece V. An image of the distant object OP would be formed by the mirror EF, in some place behind D : but the rays being reflected, it is formed at H, and is magnified by the lens V.

FIG. 224.



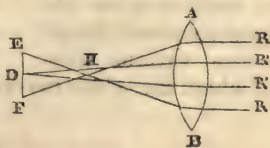
99. The reflector D, and the eye-piece V, are moved along the great tube—so as to adjust the instrument for objects at different distances [74].

100. Images, formed by refraction, are more or less indistinct, on account of the production of colours—for reasons to be explained hereafter : those produced by reflection are free from this inconvenience. Also, a lens, having the same focal length as a mirror, must have a greater curvature. The focal length of a plano-convex lens, for instance, is twice the radius, while that of a concave reflector is but half the radius :—when, therefore, their focal lengths are equal, the curvature of the lens is four times as great as that of the mirror.

101. Sir D. Brewster gives the following method of finding the magnifying power of any telescope.—“Having put up a circle of paper, an inch or two in diameter, at the distance of about 100 yards, draw upon a card two black parallel lines, whose distance from each other is equal to the paper circle. Then view—through the telescope—the circle, with one eye, and the parallel lines with the other ; and at the same time, let the parallel lines be moved nearer to, or farther from the eye, till they seem exactly to cover the circle. The quotient obtained by dividing the distance of the paper circle by the distance of the parallel lines from the eye, will be the magnifying power of the telescope.”

102. SPHERICAL ABERRATION.—We have supposed that, when lenses or mirrors are used, all the rays meet at the focus :—this, however, is not the fact. The distance between the farthest and nearest points D, and H, fig. 225, at which the rays intersect each other, is called the *longitudinal aberration* ; and EF, the distance to

FIG. 225.



which the rays RR have diverged before $R'R'$ have come to a focus, is called the *lateral aberration*.—The term “spherical aberration” is used, because it arises from the sphericity of the lens, &c.

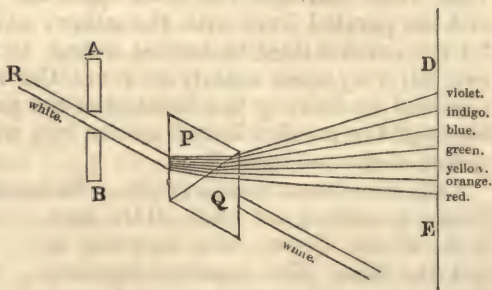
103. We may illustrate spherical aberration, by covering first the centre, and then the circumference of a lens :—we shall find that the focus obtained in the former, will not be the same as that obtained in the latter case.

It is evident that, when a mirror is used, parallel rays, R,R , fig. 215, cannot meet at one point F , except the lines representing the incident and reflected rays, make equal angles with perpendiculars to the curve—which will be the case only when the latter is a parabola [pneum. 100]. When the rays are divergent they cannot come to the same focus, unless the mirror is part of a figure generated by the revolution of an ellipse on its major axis ;—and then, when the luminous point is in one focus, the rays will converge to the other [pneum. 101].

104. Since [100] a mirror having the same focal distance as a lens, is not nearly so spherical, it is not so much affected by spherical aberration.

105. CHROMATICS.*—We have not hitherto supposed that light is capable of being resolved into elements : and, before Sir I. Newton discovered that white light is formed by a union of the different coloured rays, and devised a means of decomposing it, the production of the different colours was explained by most absurd suppositions. During his experiments, however, on the nature of light, Newton found that the different colours are not refracted to the same focus : and that the consequent production of coloured images was one of the most serious obstacles to the perfection of the refracting telescope [100]. It must, at first sight, appear strange that white light should be a compound of all the colours : but this may be demonstrated both analytically, and synthetically, by experiment.—If a ray R , fig. 226, passing through the aperture in a window shutter AB , is thrown on a triangular prism P , it will form on a screen DE , placed to receive it, an oblong coloured image—the various tints of which the white ray was composed, being differently refracted,

FIG. 226.



* *Chrōma*, colour. *Gr.*

the violet most, and the red least. A second prism Q, exactly like P, will reunite all the coloured rays, and combine them again into a white one. The oblong image of the sun, formed on the screen, is called the *solar spectrum*; and, within certain limits, the smaller the aperture in the shutter, the brighter its colours will be.—Seneca remarked the production of colours, when the sun's rays are made to pass through an angular piece of glass.

106. In reality, blue, red, and yellow are the only colours present, the rest being combinations of them. For the spectrum consists of a layer of each of these colours, superimposed on the others—the blue, the red, and the yellow appearing at those points, at which they are most vivid in the superimposed and corresponding layers.

107. Some white light is to be found along with the coloured, in every part of the spectrum;—for, at every part of it, there are the constituents of white light, plus an excess of the predominating colour. If we absorb this excess, white light, which may be decomposed by absorption but not by refraction, will remain.

108. It can be proved synthetically, that white light is a combination of coloured rays, by dividing a circular card, with radii, into compartments of a size respectively proportioned to the extent of the different colours in the spectrum: and then putting in each division its proper tint. If the card is rapidly twirled round on its centre, it will appear nearly white: and would be perfectly so, if the arrangement of colours were quite correct.

109. The following are measures of the different colours of the spectrum, as made by Fraunhofer with a prism of flint glass, the entire spectrum being considered as divided into 360 parts.

Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
56	27	27	46	48	47	109

110. The following are the indices of refraction for the different colours, with crown, and flint-glass:—

—	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
Crown glass,	1·5258	1·5268	1·5296	1·5330	1·5360	1·5417	1·5466
Flint glass,	1·6277	1·6297	1·6350	1·6420	1·6483	1·6603	1·6711

111. The three colours of which the spectrum [106] is really

composed, are thus divided among the seven, which it contains. Calling red rays R, yellow Y, and blue B—

White.	Red.	Orange.	Yellow.	Green.	Blue.	Indigo.	Violet.
20 R. + 30 Y. + 50 B.	8 R.	7 R. + 7 Y.	8 Y.	10 Y. + 10 B.	6 Y. + 12 B.	12 B.	16 B. + 5 R.

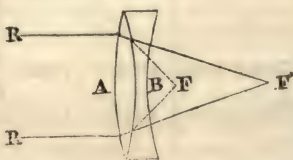
The coloured spaces of the spectrum do not always bear the same proportion to each other:—this is called the “irrationality” of the spectrum.

112. Dark parallel lines are seen across the spectrum, when it is carefully examined: their number and position are different with light from different sources, or from the same source but transmitted through different media. Thus, the vapour of iodine adds to their number; and gaseous nitrous acid makes them so numerous that, when the gas is heated, it becomes opaque, the spectrum being entirely obliterated. These lines show that rays of certain refrangibilities are absent. Altering the prism, alters their position, but does not change their relative distances.

113. The violet rays are called the “most refrangible,” and the red, the “least refrangible rays.” The angle, made by the green ray with the original direction of the decomposed white ray, is called the “mean refraction” of the prism. The extent to which the different rays of light are separated by a prism, is called its “dispersive power.” With water, the index of refraction for the red rays is 1.330, and for the violet 1.344:—the difference is, therefore, 0.014. With flint glass, the index of refraction for the red rays is 1.628, and for the violet 1.671:—the difference is, therefore, 0.043. The dispersive power of flint glass is, by consequence, three times as great as that of water; and hence, it will produce a spectrum three times as broad. A substance may have a greater refractive, though not a greater dispersive power, than another.—Thus, the mean refractive powers of flint and crown glass differ but little, while the dispersive power of the former, is almost twice as great as that of the latter.

114. The knowledge of this fact enables us to produce combinations of lenses, which are nearly *acromatic*.* The dispersion caused by the convex lens A, fig. 227, made of one kind of glass, is corrected by the concave lens B made of another: and the curvature of the latter, though it diminishes, is not sufficiently great entirely to take away the convergency of the rays:—

FIG. 227.



*A, privative; and *chrōma*, colour. Gr.

for, while without B, their focus would be at F, when B is added, it is merely removed to F'.

115. Mirrors are attended [100] with the great advantage of having no dispersive power.

116. PROPERTIES OF THE SPECTRUM.—The spectrum, as we have seen, consists of seven colours, reducible to three. In addition to these, it contains invisible rays which are either *calorific*, or *chemical*, in their action. Scheele remarked that chloride of silver is blackened by the violet, but is not affected by the red, or the yellow rays. And Ritter of Jena, in 1801, observed, that the chloride was blackened by invisible rays beyond the violet. Herschel noticed that violet glass intercepts calorific rays.

117. The calorific rays increase from the violet to the red, but extend beyond the latter; the chemical increase from the red to the violet, and extend beyond the latter. The position of the calorific rays is different, with different prisms. When crown glass is used, they are, principally, in the middle of the red space; with a hollow prism containing sulphuric acid they are in the orange: and with one containing oil of turpentine, or water, they are in the centre of the yellow space.

118. It is not improbable that light and heat are modifications of the same thing:—flame, when it first becomes visible, is violet: and it is white, only when the heat has become very intense. It is possible that the calorific rays are invisible, because our organs are imperfect, and not because they differ in their nature from those which are coloured:—they may, like sounds, be imperceptible to some animals [pneum. 70], but appreciated by others. The chemical and calorific invisible rays are capable of reflection, refraction, and polarization.

119. The chemical action of light is very remarkable. It bleaches, by causing the oxygen of the atmosphere to unite with the colouring matter. Nitric acid is decomposed, by light. If equal volumes of hydrogen and chlorine are exposed to direct solar light, they combine, with explosion and the evolution of intense heat—just as occurs, when the electric spark is passed through, or spongy platina, &c., is introduced into them. Prussian blue exposed to the direct rays of the sun, loses its oxygen and becomes white; but regains oxygen and its colour, in the dark. Crystallization requires light.—If a dish, half covered with paper, and containing the solution of a salt, is set aside to crystallize, but few crystals will form in the dark part, though there may be abundance of them in that which is not covered. Long exposure to light, decomposes peroxide of mercury into metallic mercury and oxygen. But, among all the remarkable effects which are found to be produced by light, there is, perhaps, none which has led to such wonderful results as the black-

ening of some of the salts of silver by its action. This fact has given rise to photographic* or photogenic† drawing.

120. PHOTOGRAPHY.—It was known, even to the ancient alchymists, that a substance, washed with the solution of a salt of silver and then with a solution of common salt, would become black. If a paper wetted with a solution of common salt, or—what is better—bromide of potassium, and afterwards, with a solution of almost any of the salts of silver, is held opposite to the lens of a camera obscura [44], or behind an engraving on paper, &c., and rays of light are transmitted through them for a sufficient length of time, by holding them against a pane of glass in a window, &c., the light will cause a proportionate darkness in the salt of silver which is on the paper; and the shadows will be expressed by lights—what is called a “negative picture,” being produced. If this could be used instead of the original engraving, &c., it would give a “positive;” but, unless the lights and shadows are fixed, exposing it to the light, would have the effect only of blackening its entire surface, and completely obliterating the negative picture, before a positive one could be obtained.

121. Several persons, among others, Wedgewood and Sir H. Davy, attempted to remove this difficulty; but without success, until Niepce and Daguerre‡ made their experiments.—As a reward for their important discovery of a method for fixing the picture obtained by means of the camera obscura, the French Government gave to the former a pension of 4,000, and to the latter of 6,000 francs, on condition that the details of the method adopted by them should be made public.

122. For the purpose of obtaining a picture by the daguerreotype process, silvered copper plates are generally employed: and, since it is necessary that the coating of silver should be as pure as possible, they are often manufactured by means of the electrotype process, which I shall describe when treating of galvanism. They require the highest possible degree of polish, and must be *absolutely* clean:—inattention to this condition is a frequent cause of failure.

123. The plates are cleaned with rotten stone, or very fine tripoli—on the large scale, by a lathe, or other machinery, but on the small, by hand. The rotten stone may be prepared by pounding it in a mortar, throwing the result into a vessel of clean water, allowing it to stand for a while that the coarser particles may subside, and then pouring off the fluid containing, in suspension, the impalpable powder—which, after some time, falls to the bottom, so that the water above it may

* *Phōs*, light; and *grapho*, I write. *Gr.*

† *Phōs*; and *ginomai*, I produce. *Gr.*

‡ From whom the process has been called the “Daguerreotype.”

be easily removed, and it may be dried on a plate, at the fire. Some of this powder is to be tied up in a piece of muslin, whence it can be shaken, according as it is required. Rotten stone and sweet oil is to be rubbed on the silvered plate—which, unless quite free from blemish, is useless—with a bit of well-carded cotton, and in a circular direction, until it is perfectly clean and, if it has been used before, until all traces of the former picture have disappeared.

124. The oil and rotten stone must next be wiped off with a piece of clean cotton, and the plate must then be rubbed on cotton velvet, until it has acquired a fine black polish. After this, it appears to be quite clean, though in reality it is not so. The residue of the oil must be removed by carefully heating the plate with a spirit lamp.—If heated too much, it will not, afterwards, have the proper polish, but will contain a number of white spots, which will appear in the shadows of the picture. The thinner the plate, the less it must be heated. When it has cooled, some rotten stone or tripoli must be moistened with a little alcohol or water acidulated with nitric acid, and spread over it. To avoid the necessity of heating, particularly if the plate is thin, the oil may be dispensed with: but a longer time will then be required for the process, and instead of the alcohol or dilute nitric acid, which, unless carefully used will produce stains, we may employ a weak solution of caustic potash, or even pure water. When the plate is clean, it ought to have an even gray surface, and, if breathed on, should condense the vapour in a uniform sheet.

125. The plate, after being cleaned, is to be polished with a *buff*, which consists of a piece of wood AB, fig. 228, about 14 inches long, covered with clean cotton velvet D, and slightly curved—on account of the direction which the hand necessarily takes in using it, when held by the handle H. The plate being laid on the left hand, or held by some contrivance for the purpose, a little prepared charcoal is to be thrown on the buff; and, after a while, the only pressure used, must arise from the weight of the buff itself:—the last polish should be given *across* the intended picture.



126. The plate is now ready for the iodine, and for the sensitive mixtures. Only the former was used by Daguerre; the latter were discovered since. The plate should be buffed just before it is exposed to the iodine:—the advantage of this is believed to arise, from its temperature being raised by the friction. To prevent moisture from being deposited on it, some persons even place it in a stove for a short time after the

buffing. Particles of dust may be removed, by brushing lightly with cotton wool.

127. Plates should be kept in a box, such as that which is represented, fig. 229 :—the grooves prevent them from rubbing against each other. The same box should not be used for clean plates, and for those which have iodine, &c., upon them.

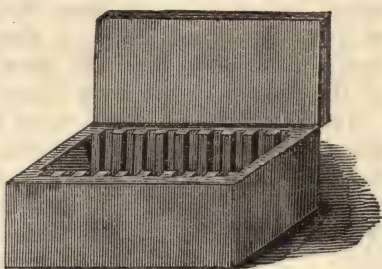


FIG. 229.

128. A few crystals of iodine being laid on the bottom of the porcelain pot A, fig. 230, the perfectly clean and polished plate is to be placed, with the silvered side downwards, in B an aperture of D, the wooden cover of A :—it is prevented from falling through B, by slightly projecting slips of glass, cemented at the under side of the aperture. The smaller lid E being shut, the cover D, having the plate within it, is to be put over A. The iodine ascends in vapour, and covers the under, or silvered side, with a coating, the colour of which depends on its thickness—being first yellow, then, in succession, golden colour, deep blood red, pale rose, and blue : after which the colour almost disappears : then becomes yellow again, and passes through the other shades, in the same order as before. It is not necessary, but it is more convenient, to iodize the plate in a dark room : a ray of light may be thrown upon it, from a sheet of white paper—the colour of the coating will then be reflected to the eye, and easily ascertained.

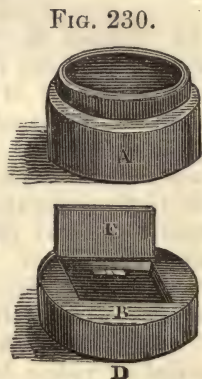


FIG. 230.

129. If iodine, only, is employed, the process is exceedingly slow. Bromine is used to accelerate it, and, sometimes also, chlorine, compounds of chlorine with iodine, &c. :—but from the difficulty of forming and keeping these of a uniform composition, their application is generally attended with more or less of uncertainty, as to the period during which the exposure to light, required in the subsequent part of the process, should be continued. Bromine water is, perhaps, everything considered, the most convenient of all the substances, which have been tried. It is prepared by putting into a glass stoppered bottle nearly full of water, a few drops of bromine, and shaking the mixture. The saturated solution, thus obtained,

which is of a bright red colour, is to be poured off from the undissolved bromine, and added to about forty times its bulk of water.

130. When the plate has been iodized, it is put into an apparatus similar to what is represented fig. 230, the porcelain vessel of which contains some of the diluted bromine water, just mentioned. The bromine, ascending to the plate in vapour, will continue to change its colour, in the same way as if it had been left over the iodine. After the bromine has been applied, the plate must be again iodized.

131. The following are the colours which are found to produce the best results: those in the same horizontal line belong to the same process—

1st Iodine.	Bromine.	2nd Iodine.
Straw colour,	Yellow,	Full yellow.
Light yellow,	Golden yellow,	Rose.
Golden yellow,	Light rose,	Deep rose.
Blood red,	Damask rose,	Light blue.
Damask rose,	Deep rose,	Blue.
Deep rose,	Light blue,	Beginning of 2d yellow.

132. If there is too little bromine, in proportion to the iodine, the plate will not be sensitive; if there is too much, in trying to “bring out” the picture with the vapour of mercury, during the after part of the process, it will be *solarized*—that is, the brighter parts will have a very disagreeable bluish tint. Too much bromine also diminishes the sensibility, and causes the mercury to attach itself to every part of the picture, so as to cover it as it were with a veil.

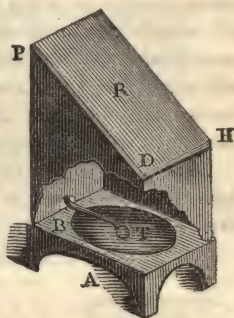
133. The second iodine having been applied, the plate is now ready for the camera obscura [44], which in this case contains no mirror AE, fig. 207, the picture being thrown on the silvered plate, &c., fixed in grooves, at the end A. The focus should be so adjusted that the landscape, &c., will be clearly seen on the muffed glass, when it is made, temporarily, to occupy the place of the prepared plate. And the lens must afterwards be moved in about the one-thirtieth of its focal distance; since the focus of rays, best adapted to vision is that of the yellow; while the focus of those best suited to chemical effect, is that of the violet [110], which is at a less distance from the lens.

134. The muffed glass of the camera is now to be removed; and the frame containing the plate, is to be put into its place—a movable shade being in front of it, to preserve it from the action of the light, except at the proper time. When the plate has been exposed sufficiently long, the shade being replaced, it is to be removed from the camera, and put into a box like

what has been already represented, fig. 229; and in which it may be kept as it is, if the light is excluded, for a considerable time.

135. Or it may, *at once*, be placed in the *mercurial apparatus*, which consists of a wooden box, fig. 231, having a sheet iron bottom B containing a hollow T—for the mercury in which the bulb of a thermometer is immersed, its scale and stem, being in front of, and outside the box. The inclined cover PH is movable, and contains on its under surface, small slips of iron, which at three sides confine the daguerreotype plate, while its silvered side is exposed to the vapour of the mercury, and allow it afterwards to be easily removed.

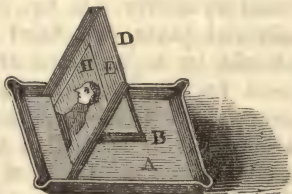
FIG. 231.



136. Before the mercury has begun to condense on the plate, the picture is quite invisible; but it is *brought out* completely, when exposed sufficiently long to the mercurial vapour. That the latter may ascend with sufficient rapidity, a spirit lamp is placed under T, until the thermometer stands at about 150° .

137. When the plate is removed from the mercury, the sensitive coatings must be taken away, or the picture will be destroyed by exposure to light. For this purpose, it is held by one corner, in a pair of pliers, and is suddenly immersed, the picture being upwards, in a solution of hypo-sulphite of soda, containing half an ounce of the salt to a pint of distilled water: and, when the colours due to the coating have disappeared, it is plunged into distilled water: and, after that is placed on the tin stand D, fig. 232, which rests in a porcelain dish A, and has a small slip of the metal at its lower edge—to prevent the daguerreotype plate from falling off, but at the same time allow it to be removed with great facility. Hot distilled water being poured over the plate while on the stand, it is to be dried rapidly by a spirit lamp, held behind it, and first applied to the highest corner, but gradually brought down, until there is, at the lowest, only a single drop of moisture—which may be removed, by touching it with blotting paper. A bellows may be used instead of the spirit lamp, to drive the moisture down, and dry the plate.

FIG. 232.



138. If the picture is to be *fixed* with gold—and without this, the slightest touch defaces it—fifteen grains of the double salt, called the hypo-sulphite of gold and soda, are to be dissolved in

a pint of distilled water: or, fifteen grains of crystallized chloride of gold are to be dissolved in a pint of distilled water, and mixed with a solution, containing forty-five grains of hypo-sulphite of soda in a pint of distilled water—the solution of gold being gradually poured into that of the soda, kept stirred during the time. While the plate is still wet with the distilled water, it is to be put on a stand, so as to be in a horizontal position; and a small quantity of either of the above gold solutions is to be dropped upon it, through a funnel containing filtering paper, until any more would flow over the edges. A lighted spirit lamp is then to be moved about under it, so as to heat all parts of it alike. Bubbles will form, and the image will become darker: but it will afterwards brighten, and the lights and shades will be rendered more intense. As soon as this occurs, the gold solution should be poured off, and the plate should be washed with distilled water. Gilding with a weaker solution of gold than the above, will allow the heat to be applied longer during the process, and will sometimes banish stains, unless they arise from oil, left in the cleaning—in which case they will be white, and will become worse and worse. Continuing the heat, sometimes removes “solarization” [132]: but the better way is to deposit on the plate a thin coat of silver, by the electrotype process—to be described hereafter.

139. Arago believes the result of the photographic process due, in some degree, to electricity; since it is more perfect when copper and silver, than when pure silver is used. It has, also, been supposed that the angle, at which the plate is presented to the current of mercurial vapour, bears an important relation to the amount of effect obtained. The picture on the plate is produced by the mercury forming an amalgam with the portions of the silver from which the iodine was driven off, through the action of the light. The clean metallic surface forms the dark parts: the intermediate effects are caused by the iodine being driven off less perfectly, in the fainter light—and the consequent formation of more minute quantities of the globules of amalgam. I must, however, remark, that a satisfactory explanation of the process has not, as yet been given. It is certain that red or yellow rays will obliterate a picture, and restore the sensitiveness of a plate, after it has been in the camera, and before exposure to the mercury: which throws a doubt on the fact of iodine having been removed.

140. The brighter the light, the more rapid its action; but moonlight, or even that from a lamp, or candle, may be used:—the oxyhydrogen lime-light, or that from the galvanic battery, answers extremely well. But, since red light, or green—as it contains yellow—is ineffective in the daguerreotype process [139], the latter does not answer well for landscapes, the green

portions of which produce merely a shade : and, in portraits, a disagreeable expression is given to the mouth, on account of the darkness arising from the redness of the lips.

141. Even the smallest picture obtained by the camera is, in reality, distorted, since the foci of lenses and mirrors [28, &c.] do not lie in plane, but in curved surfaces ; and when the daguerreotype plate is large, the distortion at the outer portions, is very perceptible. Placing at some little distance in front of the lens a *diaphragm* or shade having a circular opening to admit the light, is attended with a very good effect ; diminishing the aperture renders the picture sharper, but makes it require a longer time in the camera.

142. Perfect steadiness in the object to be copied, is necessary in the daguerreotype process :—without this, the picture will be confused, on account of there being, as it were, two or more images, superimposed but not quite co-incident. Hence, it answers extremely well for copying paintings, engravings, or statutes. When portraits are taken by means of it, the head is generally made to rest against a stand attached to the back of the chair on which the person sits.

143. The attempt to colour daguerreotype portraits, while producing them, has not been attended with success. The colours, sometimes given to them, are applied mechanically.—Although there is, no doubt, some tendency in the rays of light to produce their own tints on the plate, those obtained are generally very different from what belong to the objects ; and all that can be considered under our control is the *general tint*.

144. PHOTOGENIC PROCESS WITH PAPER, &c.—Silvered plates being very expensive, it is desirable to obtain a cheaper material. Paper has been, of late, very much employed, and with considerable success. The mode of using it, discovered during some experiments on the subject, by Mr. Talbot, was termed by him the *calotype* :* but it has been called, after him, the “ Talbot-type.”

145. One of the most difficult matters, attending this process, is the selection of the paper : which must be quite uniform in thickness : while, unfortunately, most paper, if held between the eye and gas or candle light, exhibits irregularities in thickness, and sometimes even holes. Many kinds, also, contain sulphate of lime (plaster of Paris), which is highly objectionable. The colouring matter of bluish paper is very injurious. What is used for the calotype, should be well sized, as the organic matter renders it sensitive ; but, if it has been recently made, the size will not be sufficiently hard and insoluble.

146. Paper, brushed over with a solution containing 100 grains of crystallized nitrate of silver to an ounce of water, will

* *Kalos*, beautiful. *Gr.*

blacken with an hour's exposure to the sunshine, and will answer well for copying lace, &c. All the undecomposed nitrate may be washed out, by soaking it in hot water.

147. If sixty grains of common salt are dissolved in three ounces of distilled water: and paper, which has been dipped in the solution, is pressed between folds of bibulous paper, and then evenly and rapidly brushed over with a solution containing sixty grains nitrate of silver to an ounce of water, a very good material will be obtained.—It must, of course, be dried in the dark. In this process, some of the nitrate is not changed to chloride of silver, which increases the sensibility; for neither chloride, iodide, nor bromide of silver are sensitive, when quite pure. Increasing the quantity of common salt increases the sensibility; but it injures the colour—which it makes a dark slate instead of a rich bronze. If sixty grains of bromide of potassium are used instead of the common salt, and one hundred instead of sixty grains of the nitrate of silver, a very sensitive paper will be produced:—and its sensibility will be increased, by a still larger quantity of the nitrate. If chloride of barium is employed instead of the common salt, a deep red ground will be the result. Various other substitutes for it have been tried.

148. The best method perhaps of all, is to wash the paper with a solution, in which thirty grains nitrate of silver have been dissolved by an ounce of distilled water—as much water of ammonia having been added, as will dissolve nearly all the oxide of silver, at first thrown down. It must not *all* be dissolved, since, then, the ammonia might be in excess—which would destroy the sensibility of the paper. The solution may be freed from undissolved oxide, by being allowed to rest for a while: after which the fluid above it, may be poured off. The prepared sides of the paper—which ought not to be touched with the fingers, lest an impression of them appear, afterwards, along with the picture—should be marked; and it should be used within a few hours after having been made.

149. To copy an engraving, &c., it must be pressed close to the paper, and the light must be transmitted through both. This, as the lights and shades are reversed, will produce a *negative* picture; but if the latter is employed along with another portion of the prepared paper, instead of the engraving, &c., it will give a *positive*. The negative picture must be *fixed* before being used; or, as is evident, the whole will become dark.

150. A negative, or positive picture, may be fixed, by dissolving out, with a solution of hypo-sulphite of soda, the undecomposed salt of silver—after washing the paper with hot water, and pressing it between blotting paper. Only the back

of the paper should rest in the hypo-sulphite—which will then permeate the entire, by degrees and without injury to the picture. After being taken out of the hypo-sulphite, it must be placed, for some time, in *cold* water; for, allowing any hypo-sulphite to remain would destroy it, by forming sulphuret of silver—which would be produced, at once, by hot water. It is finally dried, by pressing between blotting paper. Light, in decomposing the silver salt, first forms oxide, and then metallic silver:—the oxide will be dissolved, by washing with cyanide of potassium. Red light [139] will restore paper blackened by violet.

151. Washing a picture in the solution of corrosive sublimate, entirely obliterates it; but it may be restored, at any time, with the greatest facility, by washing it with hypo-sulphite of soda.

152. *The calotype*.—The papers prepared as I have described, may be used in the camera, instead of plated copper [122]; but they require a very long time for the production of a picture:—the effect in the calotype process is, on the contrary, extremely rapid. For this purpose, the paper is to be laid on a board, with two or three sheets of blotting paper under it, to absorb any moisture which may run over the edges. It is then to be washed—by candlelight—with a solution containing about twenty grains nitrate of silver to an ounce of distilled water, and dried at a little distance from the fire. It is next to be entirely immersed, for about half a minute, in a solution containing 250 grains iodide of potassium, 125 grains common salt, and 125 grains bromide of potassium, to a pint of water.—If the immersion is not continued sufficiently long, some nitrate of silver will be left undecomposed, and the paper will blacken spontaneously: if it is continued too long, the iodide of silver will be dissolved out by the iodide of potassium. The paper is next to be well washed with water, to remove the excess of iodide of potassium, &c., then dried and preserved from the light.—It is washed sufficiently, when a drop of water, falling from it into a solution of nitrate of silver, does not cause any cloudiness.

153. This paper is to be rendered sensitive, just before being placed in the camera. For this purpose, a small quantity of a mixture consisting of equal parts of two solutions is to be poured on a sheet of plate glass, made horizontal by adjusting screws so that the liquid will not run off.—One of these solutions contains 100 grains of crystallized nitrate of silver, dissolved in two ounces of water, and added to one-sixth of its bulk of strong acetic acid:—the other, as much gallic acid as will be dissolved by cold water.—The former must be kept in a bottle, from which light is excluded: and the two should be mixed just before being poured on the

plate of glass. The prepared face of the iodized paper is to be laid in the fluid on the glass, the air bubbles between being gently pressed out, by applying the finger to the back of the sheet: and, when the edges have ceased to curl up, it is to be put between the folds of blotting paper, and very gently pressed, so as to remove any shining patches of moisture from its surface. To prevent its blackening spontaneously, it is to be immersed for an instant in water, that the solution it has imbibed may be weakened: or the mixture itself may be rendered less strong before using it, by dilution with about twenty times its bulk of water:—the longer it is to be kept, the weaker the solution ought to be. If the acetic acid is too weak, the paper will blacken all over during the process, or will become of a dirty colour; if too strong, its sensitiveness will be destroyed.

154. The paper thus prepared, is next to be placed in the camera: and, having been left in it during the time which experience has shown to be sufficient, it is to be taken out, and again washed on the plate of glass, with the mixture before used; after which, it must be exposed to a gentle heat—if possible, to a jet of steam, which brings out the picture, before invisible. If a jet of steam cannot be conveniently obtained, that which arises from a basin of hot water will do very well. While the different parts are being brought out, the paper must not be allowed to dry—which may be prevented, by re-wetting it with the mixture on the glass.

When the picture is brought out, the paper is to be agitated in plain water, renewed once or twice: then dried in blotting paper: and fixed by immersion in a solution of hypo-sulphite of soda: after which, it is to be first washed several times, then soaked for two or three hours in water, and dried between blotting paper.

155. A positive picture may be obtained from the negative, with paper prepared in the same way: but it is better to use some of the other kinds, already described.

156. With this process, the impression of a leaf, &c. may be produced by the light of the moon, or that from a candle or lamp, in a few minutes; with sunlight the effect is instantaneous.

157. In obtaining a positive from a negative picture, when the light is very powerful, it is useful to interpose one or more sheets of clean paper, to soften it.

158. *The Fluorotype, &c.*—In this process, fluuate of soda is one of the substances employed; and the impression is rendered stronger, by washing with a weak solution of protosulphate of iron. Whenever the latter substance is used, the process is called *ferrotype*.*

* *Ferrum*, iron. *Lat.*

159. The terms *chromatype*, &c., indicate various substances, also employed; but the processes are not sufficiently important to require a description here.

160. Sir J. Herschel discovered that, if a solution of nitrate of silver spec. grav. 1.200 is added to ferro-tartaric acid spec. grav. 1.023, the precipitate which falls being re-dissolved by applying a gentle heat, and paper wetted with the solution is exposed to sunlight for about 30', an engraving being interposed, the impression will develop itself, even if the paper is removed from the light:—but if, before this occurs, it is dried in the dark, the impression will appear, as if by magic, when the picture is breathed upon.

161. A drawing may be transferred to wood, in the manufacture of wood cuts, by washing the surface of the wood, and treating it in the same way as if it were paper. Similar methods have also been applied to the production of drawings on stone: but the manner in which this is effected, has not been made public.

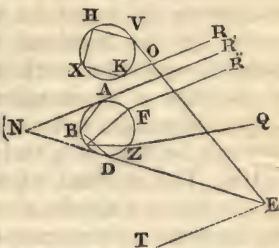
162. The processes I have just described, although founded on the action of light, and therefore conveniently introduced into Optics, are intimately connected with Chemistry: they will, therefore, be understood better, when that branch of knowledge shall have been studied, in the second part of this treatise. I have carefully avoided any chemical explanation, or any technicality, which might render the subject unnecessarily difficult.

163. THE RAINBOW is formed by the decomposition of light, caused by the particles of moisture acting as minute prisms. Since the coloured rays, which form white light, are differently refracted, they cannot enter the eye in a combined form: and the sensation of colour must, therefore, be produced. The rainbow constitutes the base of a cone, the vertex of which is in the eye, and its axis in a line passing through the spectator's eye and the sun, which is at his back. It may be caused by the mists of waterfalls, &c., as well as by rain. The gorgeous masses of coloured light, varying in tint almost every instant, and adding so greatly to the beauty and magnificence of the falls of the Rhine at Schaffhausen, are produced in this way: being due to the decomposition of white light, by the mist rising from so vast a body of water falling through so considerable a height:—the effect can be conceived, only by those who have witnessed it.

164. The rainbow consists merely of a number of spectral images [105] arranged in a circle. The primary or inner bow is caused by two refractions, and one reflection.—The ray R', fig. 233, is refracted at A, reflected from the inner surface, at B, and, having been again refracted at D, enters the eye at E. Many rays pass into the drop; but only those will be parallel and

produce an effect on the retina, which are incident in the vicinity of that point on its surface where, from the nature of the medium of which it consists, the incident ray $R'A$ makes the *greatest* angle with the emergent ray DE . If the situation of the drop of moisture is such, that the coloured rays emerging from it nearly parallel, will enter the eye of an observer, he will perceive the corresponding colour.—The greatest angle in rain water for red rays, emitted after one reflection, is $42^\circ 30'$; and for violet, $40^\circ 30'$. Rays like R'' incident on other parts of the surface of the drop, emerging in the direction ZQ , will be so divergent as not to enter the eye.

FIG. 233.



165. Let, therefore, ET be a line passing from the sun through E the eye of the spectator, and by consequence parallel to $R'A$: and let $TED = 40^\circ 30'$. If ED revolves on ET as an axis, D will describe the circumference of the base of a cone; and any rays in the direction $R'A$, which, during any part of its revolution, fall on the corresponding drop, will emerge in a direction E ; and, since the angle between the incident and emerging rays $= 40^\circ 30'$, they will be among those violet rays which, emerging nearly parallel, reach the eye, and produce on the retina the sensation of that colour. In the same way, if the angle $TED = 42^\circ 30'$, the emerging rays will belong to those red rays which, being nearly parallel, reach the eye, and produce the sensation of the latter colour. In this way, all the drops with which D would come into contact, were ED to revolve on ET as an axis, send to the eye at E , rays which are nearly parallel, and which taken together, form a coloured ring. The other coloured rings, will be produced in a similar manner, by incident and emerging rays making the greatest angles, belonging to them, respectively.

166. Since the sun is not a point, but a disc about $30'$ in width, the coloured rings are each about $30'$ wide: and the whole breadth of the rainbow is, on the average, about 2° .

167. Besides the primary, there is sometimes seen a secondary bow, which is outside the primary, and concentric with it: but the colours are reversed. It is produced by two refractions and two reflections: and its colours are fainter, because the more frequently light is reflected, the less intense it is. The ray R , fig. 232, enters the drop, and is refracted at K ; is reflected from the interior surface at X , and, again, at H ; thence emerging, it is again refracted at V , and crossing the incident ray, enters the eye at E . When there are two reflections, rays incident on that point of the surface of the drop which makes

the angle between the incident and emergent ray *least*, will emerge nearly parallel, and reach the eye. The least angle for red rays is 50° ; and for violet $53^\circ 30'$. If, therefore, the angle made by the incident and emerging rays $= 50^\circ$, the nearly parallel rays from each of the drops lying in the circumference of the base of the imaginary cone [165], will form in the eye at E the image of a red circle: and if it $= 53^\circ 30'$, the image in the eye will be that of a violet circle.

168. The amount of the arc, which will be visible, depends on the sun's altitude above the horizon. When the sun is in the horizon, an observer on a plane sees an exact semicircle:—on an isolated mountain top, of small breadth, he would see more than a semicircle. Rainbows, forming perfect circles, are sometimes visible from the masts of ships. The higher the sun, the lower the centre of the bow, and, therefore, the less of it is above the horizon.—If the sun's elevation is $42^\circ 30'$ and the observer is at the level of the sea, the top of the rainbow coincides with the horizon, and none of it is seen by him. Three, four, &c., rainbows, would be perceptible, if the light were not so much weakened by the repeated reflections necessary to form them, that it is no longer capable of producing any effect on the retina:—the third bow would require three, and the fourth, four reflections, &c.

There are lunar bows, likewise.

169. *Parhelia*,* called also, “mock suns,” are images of the sun, occasionally perceived at some distance from that luminary. According to Mariotte, they are due to particles of ice, suspended in the air, and multiplying the image of the sun—either on account of turning its rays out of their paths by refraction, or of reflecting them, like mirrors. *Parhelia* are apparently of the same size as the sun; but they are not so bright, nor are they always round: several having various degrees of brilliancy, may appear at the same time: and their edges are often tinged with various colours. They are sometimes seen within a coloured ring, which has been noticed also round the sun, and—of a smaller size—round the moon: and should not be confounded with halos. It is found by calculation, that frozen particles of water, in the shape of six-sided prisms, would form both the rings and *parhelia*—the latter being caused by light reflected from vertical surfaces.

170. INTERFERENCE OF LIGHT.—If a small convex lens is placed in the aperture of a window shutter one-fortieth of an inch in diameter, there will be transmitted a divergent beam in which the shadows of bodies will have coloured and parallel fringes:—this will not occur, if half the light is intercepted. Hence the rays, at one side, interfere with those at the other.

* *Para*, beside; and *hēlios*, the sun. *Gr.*

Two pencils of light may be made to cross each other, in such a way as either to increase, or diminish each other's intensity. These interferences strongly confirm the correctness of the vibratory theory; and they arise from a cause similar to that which [pneum. 98] produces interference of sounds. It is found that, when two equal quantities of red light are made to fall upon a sheet of white paper, there will be, in some cases, a double quantity of that light, but in others, no light whatever.—The double ray is twice as bright as each single ray, when the difference of the lengths of the two beams, from the two luminous points to the red spot on the paper, is exactly the 0.0000258^{th} of an inch, or some multiple of it. But if the difference is equal to the $\frac{0.0000258^{\text{th}}}{2}$, or some multiple of it, no light

will be perceived on the paper. If the difference of the lengths of the rays is equal to the 0.00003225 ($0.0000258 \times 1\frac{1}{4}$)th, the 0.00005805 ($0.0000258 \times 2\frac{1}{4}$)th, &c., of an inch, the red spot, formed by the combined beams, will be of the same intensity as that produced by only one of them.

171. When violet rays are used, the difference must be the 0.0000157^{th} of an inch: when the other coloured rays, quantities between the 0.0000258^{th} and the 0.0000157^{th} of an inch—or their multiples.

172. The interference of luminous undulations may be illustrated, by placing on a smooth table, two bits of plate glass cut from the same piece, with their divided portions in contact, and gently inclined to each other—by a piece of paper placed under the edge of one of them. If a ray of homogeneous light—yellow, for instance, from a spirit lamp with a salted wick, all extraneous light being excluded—is thrown upon them, light and dark alternate bands, will be perceived. The bright portions arise from undulations, which are in the same phases; and the dark ones, from those which are in opposite.

173. These facts enable us to explain why, if a minute opaque body, a slender wire or a pin for example, is held opposite to a small aperture in a window shutter, the light is coloured in a peculiar way. The bright bar, in the middle, is caused by the rays of equal length passing at each side; and the coloured fringes, by the oblique rays—which tend to one side or the other, and, consequently, are of unequal lengths. Black lines are formed at certain distances, by total, coloured bands, by partial destruction of the white ray.

174. If homogeneous light is used, alternations of that light and dark bands will be the result.

175. The effect produced by the interference of light, enables us to understand why coloured rings are perceived, when we look at the sun, or any other luminous body, through glass covered

with particles of dust, lycopodium, &c.:—even particles of water, deposited on the glass by breathing upon it, will cause the same effect. It shows, also, the way, in which *Halos*, or coloured circles round the sun and moon [169], are formed by interference due to particles of vapour. The sun's brightness prevents solar from being seen as often as lunar halos.

176. *Colours of thick, and thin plates, grooved surfaces, &c.*—If we diminish the thickness of glass plates, &c., beyond certain limits, white is changed into coloured light, during transmission through, or reflection from them. A soap-bubble will exemplify this fact; or two lenses of great focal length [mech. 36], screwed together so as to leave between them only a thin plate of air—the diminishing thickness of which will cause the production of different colours. The latter enable us to estimate the lengths of waves belonging to the different kinds of light.—For their colours arise from the unequal lengths of the rays, reflected at certain intervals, from each of the surfaces in apparent contact: the differences being such as to produce, through interference, the decomposition, or the total destruction of white light. And it is evident that, as we know the curves of the lenses, these differences may easily be ascertained.—The following are the lengths of the undulations, &c., according to Sir J. Herschel, deduced from admeasurements made by Newton:—

Coloured rays.	Length of waves, in parts of an inch.	No. of undulations in an inch.	No. of undulations in a second.
Extreme red, .	0·0000266	37,640	458 millions of millions.
Red,	0·0000256	39,180	477 "
Intermediate, .	0·0000246	40,720	495 "
Orange,	0·0000240	41,610	506 "
Intermediate, .	0·0000235	42,510	517 "
Yellow,	0·0000227	44,000	535 "
Intermediate, .	0·0000219	45,600	555 "
Green,	0·0000211	47,460	577 "
Intermediate, .	0·0000203	49,320	600 "
Blue,	0·0000196	51,110	622 "
Intermediate, .	0·0000189	52,910	644 "
Indigo,	0·0000185	54,070	658 "
Intermediate, .	0·0000181	55,240	672 "
Violet,	0·0000174	57,490	699 "
Extreme violet, .	0·0000167	59,750	727 "

177. The time of vibration of a given ray varies, directly as the length of the wave of that colour; and inversely as the

velocity of light. And Newton found that the thickness of the different media, at which a given colour is seen, is in the inverse ratio of their refractive indices.—Hence, knowing a tint, and the medium which produces it, we can find the thickness of laminæ, so thin as that it would be impossible to measure them, by any other means.

178. The colours produced in these experiments, do not depend on the air, since they are the same *in vacuo*: but on the interference of waves, which are in different phases, on account of the different lengths of the rays, reflected from surfaces that are extremely near each other. As light is reflected from both surfaces of any transparent medium, colours will always be seen, when that, through which we transmit it, is of such a thickness, as to cause the required difference in the lengths of the two reflected rays.

179. If oil, or water, is interposed between the lenses [176], the rings contract.

180. When the flame of a candle, &c., is viewed through two glass plates of equal thickness, making a small angle, besides the transmitted, we shall see, also, reflected images:—and in the nearest and brightest of the latter, coloured fringes.

181. If a strong light is thrown on a thick concave mirror of glass, coloured rings will be perceived.

182. Mother of pearl affords a striking example of the effects produced by grooved surfaces.—If it is stamped on heated black sealing wax, the grooves, though invisible to the eye, will be communicated to the wax, which will then present an appearance, similar to that of the mother of pearl. Steel may be cut, so as to produce the most beautiful tints.

183. All these results depend on interference; and they enable us to explain, in many cases, the colours of bodies—some of which, however, are due to the partial absorption of the rays constituting white light.

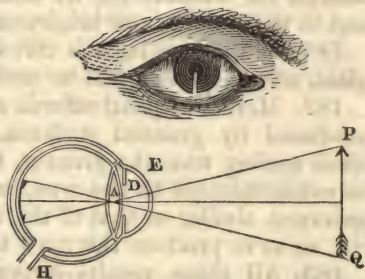
184. THE EYE, may be considered as an optical instrument, bearing a very close analogy to the camera obscura [44]. It is divided by anatomists into many parts:—we shall consider only those which are most important, so far as the present subject is concerned.

185. The eye-ball is protected by the upper and lower lids, the eye-brows, and eye-lashes. By a beautiful provision, it is exceedingly sensitive to very small, though but slightly so, to large objects:—it may be touched by the finger, with little inconvenience: while a particle of dust causes intense pain. Its power of seeing the larger bodies is a sufficient protection against injury from them; but those which are almost invisible, might still be productive of serious consequences. The moment, therefore, the latter come in contact with it, they are

wiped away by the motion of the eye-lid—aided by the lachrymal fluid; or they are removed by the finger, &c., their presence being made known, by the pain to which they give rise. Instances are recorded, in which blindness has been caused on account of the eye having been gradually and imperceptibly destroyed, by minute objects—to the presence of which, it had become insensible. As an additional security to this most important, and, at the same time, most delicate organ, it is placed in a strong socket of bone called the *orbit*. When an animal is soft and without bones, it is capable of being brought, for safety, within the body:—thus, the snail can draw in its eyes, which are placed at the extremity of its horns, whenever they are exposed to danger. The eyes of animals that are without eye-lids—such as fishes—are made so as to receive no injury from the particles, to which they are exposed.

186. The globe of the eye is surrounded by a hard membrane called the *sclerotic** coat, transparent only at E, fig. 234—the part of it which is termed the *cornea*,† and is more curved than the rest. A prismatic coloured membrane, called the *iris*,‡ lies behind the latter:—its plane cuts off the cornea, as it were, from the rest of the eye. A circular opening D, in the middle of the iris, is called the *pupil*: by its expansion, or contraction, it allows the proper quantity of light to enter. The *choroid*§ coat, is a membrane lining the sclerotic: it is covered over with a black pigment called the *pigmentum nigrum*|| which absorbs all the light that—not contributing to the production of an image within the eye—would merely tend to render it indistinct. For a similar reason the interiors of telescopes, and other optical instruments are blackened. The *retina*,¶ an expansion of the optic nerve H, receives the image. The *crystalline* humour A—a double convex lens—is placed within a transparent capsule, which attaches it to the outer wall of the eye. A clear, and somewhat saline, fluid, called the *aqueous*** humour, lies between the crystalline lens, and cornea: and the *vitreous*†† humour, which is within the crystalline lens, fills the great mass of the eye-ball.

FIG. 234.



* *Skleros*, hard. *Gr.*

† *Iris*, a rainbow. *Lat.*

|| Black pigment. *Lat.*

** *Aqua*, water. *Lat.*

† *Cornu*, horn. *Lat.*

§ *Chōra*, a region. *Gr.*

¶ *Retē*, a net. *Lat.*

†† *Vitrum*, glass. *Lat.*

187. When light falls on the front of the eye, part of it is reflected, in all directions, by the white opaque sclerotic; part of it reaches the iris, and is given back in tinted rays—blue, hazel, &c., according to the colour of the eye; and part, entering the pupil, is transmitted through the crystalline lens, and refracted in such a way that the rays coming to foci on the curved surface [28] of the retina, form there an inverted image of external objects. All this may be illustrated by the eye of an ox, or other large animal, if it is opened carefully, so as to render the retina visible, through the vitreous humour: a small inverted image of any object towards which it is directed, will then be perceived, within it. Although the crystalline humour, like any other single lens [37], produces an inverted image, we refer the different portions of objects to their proper places: for, our ideas are corrected by habit.

188. Philosophers are not agreed, as to whether it is the impression made by light on the retina, or on the choroid coat, that causes vision:—some of them believe that both concur in the effect; and some, even, place the seat of vision in the vitreous humour. It is certain, that in a particular species of cuttle fish, an opaque membrane is found between the vitreous humour and the retina; and in every eye, the point where the optic nerve enters it, is incapable of vision:—hence, the image of any object, if thrown up on that part, is not perceived.

189. The crystalline lens is more convex behind than before. Within certain limits, we can alter its convexity, so as to adapt it to objects at different distances [29].—But we possess other means of adjustment; since, it is said, that the eye, even deprived of its crystalline lens, can suit itself to different distances.

190. We are enabled, by habit, to judge of distance; but we are greatly aided by the presence of intermediate objects.—Hence, we cannot form a correct idea of distance by water. Hence, also, the moon appears largest, when in the horizon, though, in reality, its vertical diameter is then least; for the increased refraction, consequent on the greater density of the air through which the light passes, makes its lower edge seem higher than it should be, considering the position of its upper:—and, we do not estimate the size of an object, simply by the angle under which it is seen, but we take into account also its distance: hence, the moon, seen under even a less angle, seems larger, because, as there are intervening objects, we consider its distance greater than ordinary—our means of measuring that distance being more abundant. From intervening objects being invisible, the distance of a fire, at night, is not correctly estimated by an observer.

191. We often attribute a diminution of light, which arises from other causes, to increased distance;—hence, objects seem

farther off, in a fog. A person who has been blind from infancy, but who suddenly obtains his sight, has no idea of distance, and thinks the surrounding objects actually within his eye—as the picture, by which he becomes conscious of their presence, really is.

192. We judge of size, also by comparison;—a circular aperture, in the centre of a large disc, seems very different, in diameter, from one of exactly the same magnitude, in a much smaller disc. And an object, in a large church, such as St. Peter's at Rome, may appear small; while in a lesser building, it would seem immense. The very dimensions of the building itself are, as it were, diminished, when every part and every decoration is in proper proportion—since, then, no part invites attention more strongly than the rest: and our notice is not attracted to the vast extent of the edifice, by the prominence of any thing which, whatever may be its actual size, seems either too large or too small for the place in which it is situated. From this cause, it is necessary to visit St. Peter's many times, before it can be fully appreciated.*

193. As the difference of density between water and the eye, is not so great as between air and the latter, light is not turned so much out of its course by refraction [11] in passing from water to the eye, as in passing to it from air.—Hence, the eyes of fishes are extremely convex.

194. Spherical aberration [102] is corrected, in the crystalline lens, by its peculiar curvature; and by the concentric layers, of which it consists, increasing in density, as they approach the centre.—The refractive power, therefore, of its different parts, is not the same.

195. Single vision with *two* eyes arises partly, perhaps, from habit; and partly, from the fact that the axes of both eyes are directed to the same *precise* spot—in which, we feel that two different objects cannot be at the same time: and, therefore, though unconsciously, we conclude that there is but one. A very slight alteration in the shape of the eye, caused by the finger, &c., will produce a double image. And persons when intoxicated, see double, from being unable properly to manage their eyes. We may render the representation of a candle in the eye double, by looking at it while the eye is in some measure directed also to objects beyond it.—*Squinting* arises from the shutting of one eye, to prevent two images being formed by one object, through organic imperfection of vision.

196. Some insects and crustacea have more than two eyes; and many of them have a great number.—The house-fly has 4,000 lenses; 17,000 have been counted in a butterfly; 24,000 in the two masses of eyes of the dragon-fly; and 25,000, in the

* See my "Elements of Architecture," p. 167.

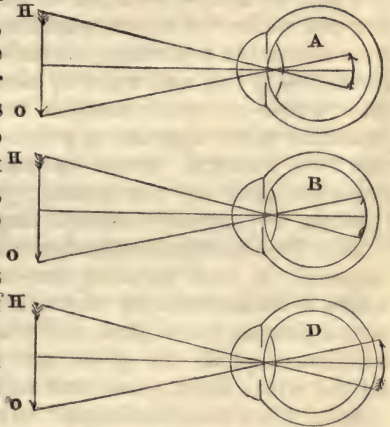
Mordella beetle. Sometimes the cornea is divided into a great number of compartments or *facettes*:—that of a single eye has been found to contain so many as 20,000.

197. LONG, AND SHORT SIGHT.—The focus of the crystalline lens is, with some persons, nearer than, and with others, beyond the retina:—the former are said to be “long,” and the latter “short-sighted.” The vision of short-sighted persons is improved by age, and that of long-sighted, made worse:—since the convexity of the crystalline humour is, in both cases, diminished by time. The eyes of short-sighted persons magnify objects—because they view them

FIG. 235.

at a smaller distance [40]. Concave glasses correct shortsight, by increasing the divergence of the rays, before they enter the crystalline lens, and thus [29] removing their focus to a greater distance. Convex

HO, when the focal length of the crystalline lens is less than, equal to, or more than it should be:—A represents short; B correct; and D long sight.



198. We can render ourselves, to a great extent, unconscious of external objects, without shutting our eyes, merely by throwing them out of focus: which—while it prevents our meditations, &c., from being disturbed by the formation of images within the eye—leaves the latter always ready for instant use; and by a certain amount of communication with the external world, prevents, in many cases, great inconvenience.

199. The faculty of memory, and the functions of the retina seem, in some way, intimately connected.—We cannot, for example, bring clearly to our recollection a building we have formerly seen, without first banishing from the retina, the image of one that is before us.

200. Sometimes, the crystalline lens is rendered opaque by *cataract*. In this case, when the disease has progressed to a certain extent, the crystalline humour is depressed by an instrument; after which, it is gradually absorbed, on account of a provision made by nature for the purpose—unless, it is, at once removed. Its place must be supplied by a lens.

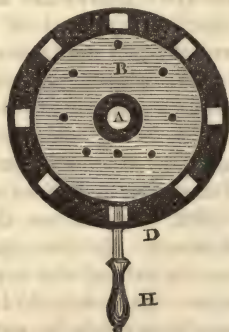
201. Some eyes are insensible to certain colours: and, when they receive white, or other light, containing them, the ray is

decomposed, and only the part which is combined with the colours to which they are insensible, becomes visible to them. Thus, when an eye is insensible to green, white light will appear red, since green and red constitute white—or, in other words, are *complementary* colours. When it is insensible to blue, green will seem to be yellow—since the latter is constituted of yellow and blue. The eye may be rendered insensible to any colour, by looking steadily at it.—If we place a red wafer on a sheet of white paper, and look at it for some time, the paper will appear covered with green spots of the same size as the wafer. That is, the surface of the retina will have become insensible to the red part of the white light, to an extent equal to the image of the red wafer. Curious mistakes are sometimes made by persons insensible to certain colours.—Thus, red silk stockings have been chosen for, and worn as black, by a distinguished philosopher whose eye was insensible to red. The same object, it is probable, never appears of precisely the same size or colour, to any two persons. Some animals may perceive rays of light, not cognizable by our senses; just as some may, it is likely [pneum. 70], perceive sounds inappreciable by us.

202. Two transparent bodies will become opaque, when superimposed, if each absorbs the colour complementary to that which is transmitted by the other. Thus a plate of red, laid over a plate of green glass, will transmit no light; since one plate will intercept all the green, and the other all the red—that is, all the white light, green and red being complementary.

203. *The Phenakistiscope*.*—Impressions which succeed each other, with a certain degree of rapidity [pneum. 75], are judged by the mind to be continuous. The “Phenakistiscope” is an optical instrument constructed on this principle.—It consists of a disc of card D, fig. 236, containing 8, 9, &c., small apertures, and capable of being made to revolve rapidly about a horizontal axis A, attached to the handle H. Within the circle containing the apertures, is fixed a smaller disc having some object, in gradually varying positions, painted upon it.—The disc in the figure, for the sake of simplicity, is supposed to represent a ball moving up and down, the dot which represents its lowest position being nearest to, and that which represents its highest, farthest from the centre; the intermediate positions being indicated by dots, gradually changing their distances from A. If—the painted side of the disc being held towards a mirror, and the whole

FIG. 236.



* *Phenakē*, a deception—from *Phenakizo*: and *scopeo*, I view. Gr.

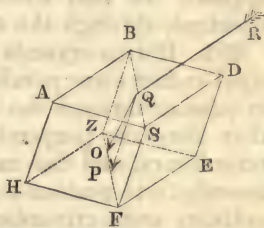
being made to revolve—the person who grasps the handle, look steadily at the mirror, through the openings, as they pass in succession before his eye, impressions of the object, in different and successive positions, will be produced; and, since one is not effaced until another is formed, the sensation will be continuous, and the ball will seem to move up and down. Any thing may, in this manner, be made continually to change its position: and thus a variety of pleasing effects may be obtained, in a way very simple, but very surprising to those who do not understand the cause.

204. The eye does not perceive objects, if their image passes too quickly across the retina.—Hence the rapid motion of a cannon ball prevents it from being seen: while a bomb-shell, which moves more slowly, is distinctly visible.

205. DOUBLE REFRACTION.—Transparent bodies generally transmit but a single image of a given object. This is not, however, invariably the case. For, some substances—such as Iceland spar—transmit two: the white ray being decomposed not into different coloured rays, but into white ones, having, as we shall find hereafter, very different properties.—This is called “double refraction.” The double image of a single object was first observed by Erasmus Bartholinus in 1669.

206. If a ray R, fig. 237, is incident perpendicularly on a rhomboid of Iceland spar, ABDEFH, at Q, it will be divided into two rays QP, and QO—the former in the direction of the original ray, and therefore unrefracted, and the latter refracted towards Z. If QR is not incident on the face ABDS, at a right angle, one of the rays will be refracted in the ordinary manner—and is therefore termed the *ordinary* ray, but the other will be turned towards an imaginary line connecting the acute angles F and B—and is called the *extraordinary* ray.

FIG. 237.



207. A plane BSFZ, passing through the two rays, is called the *principal section* of the crystal. The one, or more lines, or planes, in a double refracting crystal, in which there is no double refraction, are said to be *lines, axes, or planes of double refraction*.—There is but a *single* axis, in Iceland spar; and it is a line, connecting its two obtuse trihedral angles A, and E, fig. 236. The axis is *real* when it actually exists, as in Iceland spar. It is *resultant* when, as in mica, it arises from two doubly refracting forces neutralizing each other.—The axis is a particular direction, and not a perpendicular line; for if we separate a piece of Iceland spar into smaller crystals, each will have its axis; and the axes of all will be parallel to the original one. If

the extraordinary ray—or that which is entirely out of the plane of incidence, is refracted towards the axis, or plane of axes, it is called a *positive* axis; if otherwise, a *negative*. Quartz is an example of a positive; Iceland spar, of a negative crystal. Generally speaking, both rays are turned, not only out of the same line, but also, out of the same plane. In substances, such as quartz, Iceland spar, &c., which have only one axis, only one ray undergoes extraordinary refraction. In those having two axes, both rays are extraordinarily refracted. Doubly refracted rays, after leaving the crystal, are parallel.

208. Double refraction may be illustrated, by putting a small dot, with ink, on a piece of white paper, and laying a crystal of Iceland spar upon it:—the dot will appear double; and, on moving the crystal round, one dot will seem to revolve round the other. If we draw a black line on the paper, the two images of the line will be farthest asunder, when the line is in the same plane as the greatest diagonal of the crystal—or, in a plane parallel to it. When the crystal is turned round, the images gradually approach: and they coincide, when the line is in the same plane as the shortest diagonal—or in a plane parallel to it;—for the ordinary and extraordinary rays are then in the principal section.

Or, we may cover all but one side of the rhomb with tinfoil, and make a small hole, in the foil, over the face of the crystal opposite to that which is not covered.—On looking at the aperture, through the crystal, a double image of it will be seen.

209. If two crystals are placed together, so that their principal sections are parallel, the ordinary ray will be subdivided, in passing through the second crystal; if they are arranged so that they are perpendicular, the ordinary ray will suffer extraordinary, and the extraordinary ray ordinary refraction. In intermediate positions—unless they make an angle of 45° —the ordinary and extraordinary rays will be subdivided into rays of unequal intensity. In making experiments with the second crystal, we shall find on examination, that the two rays produced by the first, have the same properties—but, at different sides.

We can test light, which we suspect to possess the characteristics belonging to either of the rays arising from double refraction, by means of the second crystal.

210. POLARIZATION* OF LIGHT.—Under ordinary circumstances, refracted and reflected light retain their properties. But this is not invariably the case: for, it may be so modified as to be incapable of transmission, or reflection, at certain angles—and it is then said to be *polarized*. That rays of light have, in certain circumstances, different properties at their different

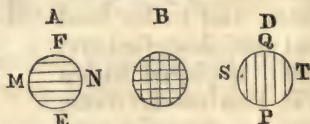
* *Polus*, a pole, *Lat.*:—because the rays of light have different properties, at their different *sides*.

sides, was remarked by Newton, in examining the rays produced by double refraction. But Malus discovered in 1808, that light may be polarized by reflection:—since that which was reflected from the windows of the Luxembourg, unlike ordinary light, gave with a rhomboid of Iceland spar, rays of very different intensity. The angle, at which light must be incident [11] on any given substance, in order that it may be polarized, is termed the *polarizing angle*, or the *angle of polarization* of that substance: a plane passing through the axis of the polarized ray, and cutting those sides of it which refuse to be reflected at the angle of polarization, is called the *plane of polarization*.

211. We may, perhaps, have some conception of the nature of polarization, if we suppose B, fig. 238, to represent an ordinary or unpolarized ray: A,

FIG. 238.

and D, its two elements. The sides of A, represented by E and F, have the same properties as the sides of D, represented by S and T. Hence, if A is incapable of reflection at a certain angle when either of the sides E and F is presented to the reflecting body, D, also, will be incapable of reflection, at the same angle, when either of the sides S and T, is presented to the same body. A plane passing through the axis of A, and at the same time through E and F; or through the axis of D, and at the same time through S and T, will be the plane of polarization of the respective rays:—these planes of polarization of the two elements are, therefore, at right angles. At a position between, for instance E and N, or P and T, the properties of the rays are intermediate—the nature of their modification depending on whether the given point is nearer to E or N, to P or T. And if the ray is incident on the reflecting surface, at these intermediate points, it will be *partially* reflected.



A self-luminous body never emits polarized light. But, it may be capable of reflecting light.—Hence, though comets emit polarized light, it is not certain that they have no light of their own [8].

212. When light is polarized, it is separated into two portions, which are produced by vibrations in planes at right angles.—Polarization, therefore, seems to reduce vibrations which, in ordinary light, occur in planes passing through the axis of the ray, and making all possible angles with each other, to vibrations in two planes at right angles.

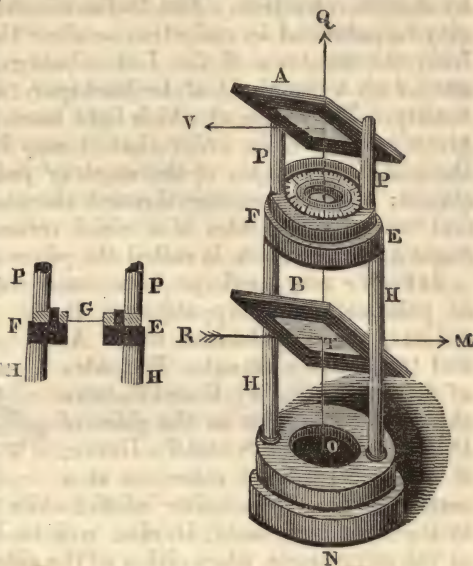
213. *Polarization, at the first surface of transparent bodies.* The “polariscope,” an instrument for polarizing light, or ascertaining if it is polarized, may be constructed like that represented, fig. 239. A stand N, having in the centre an ordinary mirror O, supports pillars H, H, to which is attached, by pins, the mirror B. The latter consists of a plate of glass—or what is better, of

several plates—fixed in a frame, and capable of being adjusted, so as to make any angle with the horizon. The upper extremities of H, H, are inserted in an annular frame, shown in section at FE, graduated at its upper surface. A similar frame, containing a plate of glass, intended as a stand or *stage* for objects, and to be used as I shall describe hereafter, is placed within FE. This interior frame can be moved round through any number of degrees—indicated by a graduated circle, on the upper surface of FE.

Outside this circle is placed another frame, which supports the pillars P, P, and is movable, also, through any number of degrees—indicated likewise, by the graduated arc on the upper surface of FE. A mirror A, fixed to P, P, by means of pins, may be adjusted so as to make any angle with the horizon.—It is evident that the planes of reflection [65] of the mirrors A and B, may be arranged so as to make any angle with each other.

214. If, while B makes an angle of $33^{\circ} 48'$ with a vertical line QO, we cause a ray R to be incident upon it [11] at an angle of $56^{\circ} 12'$, the angle of polarization for glass, part of it will pass away to M, and another part will be reflected down perpendicularly on the mirror O, and thence through the *polarizing mirror* B and the glass plate in FE, to the *analyzing mirror* A—supposed, for the present, parallel to B:—from A, it will move towards V. If, however, without altering the angles which A and B make with the horizon, A is moved round 90° , the ray thrown upon it from O, will be no longer reflected. This ray, therefore, has different properties, at its different sides; that is, it has been polarized by reflection from B. If A, is turned round another 90° , its plane of reflection will again coincide with that of B—since it has been moved round 180° : and it will once more reflect the ray, thrown up by the mirror O. At intermediate positions of A, the ray from O will be reflected by A to an extent dependent on whether, or not, the angle through which A has been moved is near either 90° , or 180° .

FIG. 239.



215. If, while the planes of reflection of A and B make with each other an angle of 90° , we cause the mirror A to make an angle of $36^\circ 46'$ with the vertical line QO, a portion of the latter will be reflected from A:—but it will cease to be reflected, from that mirror, which is now at the angle of polarization for water, if we breathe upon it.

216. Different substances have different angles of polarization—which may be found, either by experiment, or calculation. When light is polarized by reflection at the first surface, “the index of refraction is tangent to the angle of polarization:” and “the tangent of the angle of polarization is equal to the sine of the angle of incidence, divided by the sine of the angle of refraction corresponding to the given medium.” This enables us to ascertain the angle of refraction belonging to minute portions of transparent minerals: and also that of bodies which are translucent, but not transparent [6].

217. Trigonometry enables us to deduce, from this law, that—

“The complement of the polarizing angle, is equal to the angle of refraction.”

“At the polarizing angle, the sum of the angles of incidence and refraction is a right angle.”

“When a ray of light is polarized by reflection, the reflected ray forms a right angle with the refracted ray.”

218. The angles of polarization, found by experiment, agree very nearly with those obtained by calculation, as appears from the following—

Substances.	Angle of polarization, found by experiment.	Angle of polarization, found by calculation.
Air,	$45^\circ 00'$	$45^\circ 00'$
Water,	$53 \ 14$	$53 \ 11$
Fluor spar,	$54 \ 50$	$55 \ 9$
Sulphate of lime,	$56 \ 28$	$56 \ 45$
Crown glass,	$56 \ 12$	$56 \ 45$
Rock crystal,	$57 \ 22$	$56 \ 58$
Mother of pearl,	$58 \ 47$	$58 \ 50$
Iceland spar,	$58 \ 51$	$58 \ 51$
Sulphur,	$64 \ 10$	$63 \ 45$
Diamond,	$67 \ 38$	$68 \ 1$

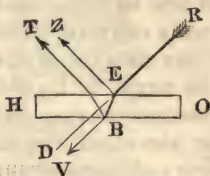
219. If the light reflected from B, fig. 239, is very intense, a coloured portion is reflected from A, even when the planes of reflection of A and B, are at right angles. This arises from some of the ray not being polarized, on account of its different coloured elements having different angles of polarization. For, with water, the polarizing angle of the red rays is $53^\circ 4'$, but that of the violet $53^\circ 19'$, the difference of the angles being $0^\circ 15'$. And, with plate glass, the polarizing angle of the red rays is $56^\circ 36'$, but that of the violet $57^\circ 55'$, the difference being $1^\circ 19'$.

220. Light may be polarized by reflection from black ebony

and other non-metallic opaque bodies. Metals, and some transparent substances, do not polarize it fully: hence, the glass mirrors which are employed to polarize by reflection, are not covered by an amalgam of mercury. The glass surface itself acts as a reflector; and it is sometimes blackened, to prevent rays from the surrounding objects interfering with its results.

221. *Polarization, by reflection from the second surfaces of transparent bodies.*—If a ray of light R, fig. 240, is incident on a plate of glass HO, part of it will be polarized, and reflected to Z; another part will be refracted to B, then reflected, and ultimately refracted to T—thus adding to the brightness of the polarized light, reflected from the first surface.

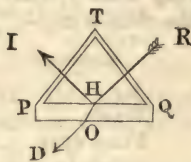
FIG. 240.



222. When light is polarized at a second surface, “the index of refraction is co-tangent to the angle of polarization.” And, as with polarization by the first surface [217], the angle made by the refracted and reflected rays = 90° .

223. *Polarization, at the separating surfaces of two media.*—When a ray is incident on the separating surface of two media, of different refractive powers, “the angle of polarization is equal to the index of refraction.” Thus, if the hollow triangular prism of glass PTQ, fig. 241, is filled with water, the ray HI will be polarized, provided RH makes with the glass plate PQ an angle = $48^\circ 47'$. For, the index of glass, the more refracting of the two substances, is 1.525; and that of water, the less refracting, 1.336.—The index of the separating surface will, therefore, be $\frac{1.525}{1.336} = 1.1415$, which is the tangent of an angle of $48^\circ 47'$. In this case, also, the angle made by the reflected and refracted rays = 90° .

FIG. 241.



224. The water must have a prismatic form, like what is represented in the figure;—for, if its upper surface were parallel with that of PQ, no angle of incidence on its first surface, could be given to the ray RH, which would make the angle of incidence on the separating surface, such as would cause polarization.

225. *Polarization, by successive reflections.*—A certain angle of incidence is, as I have mentioned [214], required for complete polarization:—but partial polarization will be produced by reflection, at any angle. This may be proved by altering B, fig. 239 so that it will make with the vertical line QO some angle differing from $33^\circ 48'$. The more perfectly the ray is polarized, at a given angle, the less of it will be reflected from the mirror A, when the latter makes the polarizing angle with the ray from O—the planes of reflection of the two mirrors being at right angles.

226. The law of tangents [216] announced by Dr. Brewster,

leads to the conclusion, that refraction takes place before a ray actually comes in contact with the refracting substance; and that the angle of polarization for every substance is, in reality, 45° .—For, if we suppose half the refraction to take place before, and half of it after the ray has become incident, it will be found that in every case the angle of incidence made by the ray is 45° .

227. *Polarization, by ordinary refraction.*—On examining the transmitted ray M, fig. 239, we shall find it to contain that portion of polarized light, which has been separated from the polarized ray, produced by reflection. And if it had passed, at the polarizing angle, through a bundle of plates, instead of through but one, it would have been completely polarized—as also the elements of opposite polarization, from which it would have been separated by reflections from the various surfaces. Hence the ray polarized by reflection will, when more than one plate is used [213], be brighter than if there were but one. The ray polarized by refraction, differs from that which is polarized by reflection, in being capable of reflection, when that which is polarized by reflection cannot be reflected; and *vice versa*.—That is, the planes of polarization belonging to the reflected and transmitted rays are at right angles.

228. According to Dr. Brewster, “the number of plates required to polarize light, at any angle multiplied by the tangent of the angle, is a constant quantity.”—That is, “the number of plates is inversely proportioned to the tangent of the angle which the ray makes with the plates; and, as will be perceived, by the following table, the observed, and the calculated numbers are nearly the same—

Number of Plates in each bundle.	Calculated angle.	Observed angle.
8, . . .	78° 52'	79° 11'
10, . . .	76 24 . .	76 33
12, . . .	74 2 . .	74 0
14, . . .	72 15 . .	71 30
16, . . .	69 40 . .	69 4
18, . . .	66 43 . .	66 43
21, . . .	63 39 . .	63 21
24, . . .	61 0 . .	60 8
27, . . .	56 58 . .	57 10
29, . . .	54 50 . .	55 16
31, . . .	53 16 . .	53 28
33, . . .	51 00 . .	51 44
35, . . .	50 23 . .	50 5
39, . . .	46 50 . .	47 1
41, . . .	45 49 . .	45 35
44, . . .	44 00 . .	43 34
47, . . .	42 00 . .	41 41

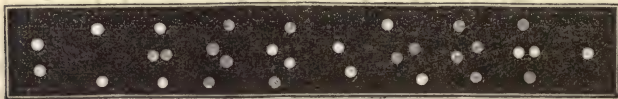
Some have supposed that plates, which are not at the polarizing angle, are incapable of polarizing light, whatever may be their number.

229. If the angle is not such as corresponds with the number of plates, the polarization of the transmitted ray will be more or less perfect, according as the angle is nearer to, or farther from the proper one. The unpolarized part is not, however, mere ordinary light:—it has suffered a physical change [225] which causes it to be afterwards more easily polarized.

230. When we examine polarized light, with a bundle of plates making the polarizing angle with the ray, if we cause the plates to revolve, as it were, on the axis of the ray, the latter will, in certain positions of the bundle, be totally, in others, partially, and, in others, not at all, transmitted by the plates.

231. *Polarization, by double refraction.*—If we examine each of the two rays, into which ordinary light is resolved by the doubly refracting crystal [206], we shall find that each is completely polarized; and that their planes of polarization are at right angles. Supposing A, fig. 242, to represent the double

FIG. 242.



A B D E F H O P N T

image of the aperture in the tinfoil [208], if the rays are transmitted through another rhomb, in contact with, or very near, the first—both rhombs having all their sides respectively parallel, as if they formed but a single rhomb—the aperture, in the tinfoil will, on looking at it through the two rhombs at once, assume the appearance indicated by B. And, if, without destroying the parallelism of the contiguous surfaces of the rhombs, we turn round the second one or that next the eye, we shall see four rays of unequal brightness, as represented at D, instead of two; turning it round still more, they will seem four also—but equally bright, as at E; turning it still further, four unequally bright, as at F; and when we have turned it round 90° , only two will be seen, as at H: turning it round still more, four will be seen, as at O; and the appearances represented by P, and N, will succeed; until when, we have turned it round 180° , we shall see but a single ray, as at T.

232. When light is polarized, by reflection from glass at its angle of polarization, it agrees in its properties with the ordinary ray of a doubly refracting crystal, the principal section of which corresponds with the plane of reflection. Consequently the plane of reflection in mirrors and the principal section of crystals have an analogous effect—dependent on the *side* of the ray, presented.

233. Partially polarized light affords two images, with doubly refracting crystals; but, unlike those produced by ordinary light, they are not of equal intensity.

234. *Polarization, by absorption.*—Some natural bodies, such as the tourmaline and agate, polarize light, in the same way as a sufficient number of plates [227] at any angle.—If a thin transparent plate of agate, is cut in a direction perpendicular to its siliceous layers, it will, when we attempt to send ordinary light through it, transmit but one of its polarized elements. On turning the agate round 90° we shall find that the element transmitted, is not the same as at first.

235. If, from a transparent crystal of brown tourmaline, which is generally crystallized in the form of a long prism, we cut longitudinally, that is, in a direction parallel to the axis of the prism—the direction of the principal axis of the crystal—a plate about the 30th of an inch in thickness, and polish it, we shall find, on looking through it at the two rays produced by the rhomb partially covered with tinfoil [208], that, as we turn it round, sometimes one, and sometimes the other of them will disappear; and sometimes both, partially.

236. We may decompose ordinary, or examine polarized light, with agate, or tourmaline:—but the former does not polarize completely, if the plate is not sufficiently thick, or if the light is too intense.

237. When the sky is obscured by but few clouds, a portion of light, in its passage to the earth, becomes polarized. The maximum of polarization occurs, in a circle about 90° from the sun. According to Arago, rays from the moon contain a large portion of polarized light.

238. We can obtain the elements of ordinary light, whether they differ in colour or in polarity, by very analogous means.—The different refrangibility of the coloured rays enables us to separate them, by means of the prism [105]; the different refrangibility of the polarized rays enables us to separate them, by the doubly refracting crystal [206]. We can separate the coloured elements, by reflection [219]; we can separate the polarized elements, in the same way [210]. We can separate the coloured rays, by absorption [183]; we can separate one of the polarized elements of light from the other in the same manner [235].

239. INTERFERENCE OF POLARIZED LIGHT.—Colours are produced by interference [170], when a polarized ray undergoes double refraction—provided the doubly refracting plate is not so thick as to produce too great a separation of the images. One of the rays emanating from the doubly refracting crystal is retarded to the amount of half a vibration: but the cause of this retardation is not well understood.

240. The colours arising from the interference of polarized light, may be illustrated, by placing on the glass stage of the polariscope, fig. 239, a thin slice of selenite, and transmitting through it polarized light. When it turned round to a certain position, the mirrors A and B having their planes of reflection parallel or at right angles, a brilliant coloured image will be seen in A: and the nature of the colour will depend on the thickness of the selenite. Whatever colour is seen when the polarizing planes of A and B are parallel, its complementary colour will be perceived if they are at right angles, A having been turned round 90° without altering the angle it makes with QO. If, without altering the mirrors, we turn the selenite round, by means of the movable glass stage, the colour will not change, but will gradually disappear, and will at length vanish, when the plane of primitive polarization passes through one of the lines termed *neutral axes*:—for the ray being then no longer divided into two, there can be no interference, nor, by consequence, any colour. On continuing the rotation of the selenite, the colour gradually reappears:—but it disappears again, when the plane of polarization passes through the second axis of the crystal. The colour is most brilliant, when the plane of polarization lies in one of the lines which make an angle of 45° with the neutral—which may be called the *depolarizing axes*.

241. The light of the sky from a window, or that of a lamp, or candle, may be used in these experiments. And the mirrors will be known to make the proper angles with the rays, when its plane of reflection being 90° from that of B, a dark spot is seen in the centre of the analyzing plate.

242. If the plate of selenite is not of uniform thickness, varying colours, dependent on the varying thickness, will be produced. Mica, &c., may be used instead of the selenite.

243. If a rhomb of Iceland spar is placed in the polariscope, on one of the faces produced by cutting off the apices of its obtuse angles, and polishing the resulting triangular surfaces, the beam of polarized light will pass along the axis, and form a series of coloured rings, intersected by a black cross, when the planes of reflection of the polarizing and analyzing plates are at right angles: but, if these planes are parallel, colours complementary to the former, and a white cross, will be produced.

244. The same results will be obtained, on transmitting light along the axis of any other *unaxial** crystal—whether it is positive, or negative. But, though the rings are the same, their properties are very different: for, if we superimpose two equally thick plates of a positive and negative crystal—of cal-

* Having but one axis [207].

careous spar, and zircon, for instance—there will be no rings; though each, separately, would produce them.

245. When a crystal has two axes of double refraction, if light is transmitted along them, there is perceived a double system of rings, combined to a certain extent, and traversed by a black cross: and if the stage of the polariscope, on which it is placed, is moved round 45° , the cross opens into two hyperbolic curves.—The dark lines, forming the cross, show where the polarized ray passes through unchanged, and are called *lines or axes of no polarization*, and, by some *optical axes*—but improperly, as all axes in crystals are optical. If the two axes of no polarization are but slightly inclined to each other—as in nitre, carbonate of lead, &c.—two systems of rings, which surround the axes, and are themselves surrounded by the same ring, may be seen at once: but if they are greatly inclined to each other—as in topaz, mica, &c.—only a system of rings surrounding each axis is perceptible.

246. The production of coloured rings by polarized light, enables to detect a doubly refracting structure, where we should not, otherwise, have been able to discover it.—Thus unannealed glass appears, in ordinary circumstances, like any other; but, placed on the stage of the polariscope, it produces a beautiful coloured image—which, unlike that obtained from quartz, is of a form depending on the figure and size of the piece experimented upon, and which perpetually assumes new and beautiful shapes, as the stage is turned round.

247. Animal jelly—when pressed with sufficient force—assumes a doubly refracting texture; and produces the tints and cross, when the planes of reflection of the polarizing and analyzing plates are at right angles. Glass, under pressure, the crystalline lenses of animals—particularly of fishes, &c.—exhibit, also, the tints of polarized light.

248. If, instead of the analyzing plate of the polariscope, fig. 239, we use a combination consisting of several plates of glass, or mica, and look down through it from above, at the crystal on the stage, we shall see colours complementary to those observed when we look from V.

If the crystal is very small, it must be placed very near both the eye, and the analyzing plate:—or a convex lens of about two inches focus may be held above it, for the purpose of throwing a magnified image on the analyzing plate.

249. CIRCULAR, &c., POLARIZATION.—If a thin plate of regularly crystallized quartz is cut in a direction perpendicular to its axis, and placed on the stage of the polariscope, on looking into the analyzing plate, in the usual way, a few rings will be perceived at the circumference of the crystal. But the centre will be of a uniform tint—provided the plate is of a uniform

thickness: and the nature of the colour will depend on the thickness. If the tint is red, when the analyzing plate is made to revolve, it will change, successively, to orange, yellow, &c., to violet: which seems to indicate that the different colours are polarized in planes lying in the direction of the radii of a circle. Corresponding effects are produced, when other tints are used.

250. Some specimens of quartz change from the red to the violet, when the plate is made to revolve from the left to the right, others, when it is made to revolve from the right to the left:—the former are termed *left handed*, and the latter *right handed*. The amethyst is composed of alternate layers of each. The thicker the plate of quartz, the larger the arc through which the analyzing plate must be moved round, to cause a change from one tint to another. This fact is seen more clearly by using homogeneous light, which indeed is most conveniently employed in many of these experiments.—If we use that from red glass, when the quartz is 0.04 inches thick, the red spot in the centre of the crystal will be brightest when the planes of reflection and polarization are at right angles; and the tint will cease to be visible, when the analyzing plate is moved through an arc of $17^{\circ} 49'$. With a crystal double that thickness, the analyzing plate must revolve through an arc of 35° . Two right, or two left handed crystals produce an effect which is the same as that of a crystal, the thickness of which is equal to the sum of their thicknesses. But, if one is right, and the other left handed, the effect will be that of a crystal which is equal to the difference of their thicknesses:—and it will be right or left handed, according as the right, or left handed used is the thicker.

251. Circular polarization is not confined to quartz; it is found also in fluids.—If a brass tube closed with glass at its lower end, and about six or eight inches in length, is filled with oil of turpentine, and placed on the stage of the polariscope, beautiful coloured images will be produced; and the planes of polarization will be found to rotate from right to left. The tube requires to be tolerably long, as the action of the turpentine is not so intense as that of the quartz. Substances between which little or no difference exists, in other respects, are distinguished by their being right, or left handed.

252. Rectilinearly may be changed into circularly polarized light, by causing it to suffer, in the interior of a glass parallel-piped, two reflections which are at angles of $54^{\circ} 30'$, and are in a plane inclined 45° to the plane of polarization of the ray:—the emergent beam will possess the properties of that which is produced by double refraction through the rock crystal [250].

253. Circular may be changed into rectilinear polarization.—Fresnel found that, if the glass parallel-piped is sufficiently

long, the light will emerge circularly polarized, after 2, 6, 10, 14, &c., reflections; but rectilinearly polarized, after 4, 8, 12, 16, &c., reflections.

254. *Elliptical Polarization*.—Circular polarization is produced by two systems of undulations of equal amplitude, polarized in planes at right angles; and differing in their paths, by the quarter of an undulation. But if the difference amounts to some other fraction, the polarization will be “elliptic.”

Elliptically polarized light is obtained, by a series of reflections, from metallic surfaces:—eight reflections from steel; and thirty-six, from polished silver, will polarize completely.

255. Elliptically may be obtained, from rectilinearly polarized light, reflected from a surface of mica, which has acquired a silvery lustre by exposure to a red heat—the plane of reflection being inclined to that of primitive polarization.

256. Elliptical, like circular polarization [253], may be changed into rectilinear, by certain intermediate numbers of reflections. Light is elliptically polarized, after 3, 9, 15, 21, &c., reflections from steel, at an angle of 86° ; but rectilinearly, after 6, 12, 18, 24, &c.

257. Some crystals possess what is termed *dicroism*;*—that is, they afford different colours, according to the direction in which the light is transmitted through them. When such crystals are placed on the stage of the polariscope, the tints vary with the inclination of the principal section to the plane of polarization.

258. Fresnel established, by experiments, in conjunction with Arago, that “two beams of light, polarized on the same plane, can produce fringes [170], by interference.” That “two beams, polarized at right angles, cannot produce them—even when brought to the same plane of polarization. But, that if they are polarized, at intermediate angles, fringes of intermediate brightness may be obtained with them.”

* *Dis*, twice; and *chrōma*, colour. *Gr*.

CHAPTER VII.

ELECTRICITY.

History of Electricity, 1.—Electrical Attraction, and Repulsion, 3.—Electroscopes, and Electrometers, 4.—Examples of Attraction, and Repulsion, 13.—Electrics, and Non-Electrics, 19.—Conductors, and Non-Conductors, 20.—The Two Electricities, 26.—Circumstances which affect the Nature of the Electricity produced by Friction, 34.—Induction, 40.—The Leyden Jar, 46.—Distribution of Electricity, 57.—The Electrical Machine, 62.—Mechanical effects of Electricity, 72.—Chemical effects, 80.—Physiological effects, 88.—Magnetic effects, 93.—Electric Light, 94.—Atmospheric Electricity, 100.—Protection from Lightning, 105.

1. HISTORY OF ELECTRICITY.—Many facts, which are now known to be connected with, and dependent on electricity, were familiar to the ancients. Thus, they were aware that amber—the Greek word signifying which* gave rise to the term electricity—has the property, when rubbed, of attracting light bodies. They knew, also, that a numbness is felt, on touching the torpedo or electrical eel; and that the human body has sometimes been caused, by friction, to emit sparks. But their knowledge did not extend beyond a few isolated facts, with the nature and causes of which they were utterly unacquainted.

2. Dr. Gilbert, of Colchester, in a treatise, “de magnete,” published in the year 1600, seems to have been the first who approximated to a correct notion on the subject. He remarked that the property of attracting light bodies, is not confined to amber. Many philosophers have contributed to bring our electrical knowledge to its present perfection:—but its great and rapid development commenced so late as the close of the last century.

3. ELECTRICAL ATTRACTION, AND REPULSION.—These were, as I have said, the first effects of electricity which excited attention: they are also the most striking, and were indeed the origin of all others. They furnish us with the means of ascertaining the presence of *free* electricity—that is, of electricity which is perceptible to the senses; and of estimating its relative amount. For we cannot place two bodies near each other, one of which is electrified and the other not, without perceiving that they first attract, and then repel each other to a greater or less distance—if their weight is not sufficient to overcome this tendency.

* *Electron*, amber. Gr.

4. ELECTROSCOPES,* AND ELECTROMETERS,† depend on the fact, that if two bodies are electrified, they will either repel, or attract each other—the former, if they are similarly, and the latter, if they are oppositely electrified. The electroscope enables us to ascertain the presence, the electrometer to measure the amount of the electricity:—but the same instrument is, very generally, applied to both purposes.

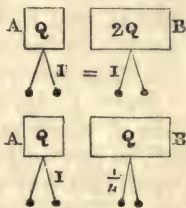
5. *The pith ball electrometer*, consists of two balls Fig. 243. A and B, fig. 243, each about the size of a large pea, formed—on account of its lightness—of the pith of elder, and sometimes gilt. They are suspended by a silk thread ADB; and, when electrified, they diverge as represented. To render this very useful instrument quite portable, the thread is sometimes fixed to a cork D, fitting into a glass tube T which, if the electrometer is in use, serves as a handle, and, if it is not, for a case—the cork being reversed.



6. It is to be remembered, that the electrometer merely indicates the *relative* amount of *sensible* electricity:—that is, of the electricity perceptible to the senses, and, the ratio it bears to the surface of the body. We can scarcely, in any case, ascertain, with more than probability, what may be the *entire* quantity of electricity present.

7. *Quantity* is the total amount of sensible electricity; it has no reference to the size of the body. *Intensity* is the energy, manifested by the particles of electricity: and has reference to the quantity, compared with the space it occupies—being due to the mutual repulsion of the particles. Let the body B, fig. 244, be twice as large as the body A. Let Q represent a certain amount of electricity; and I , a certain intensity. If in the first case, we suppose B to contain twice as much electricity as A, though the quantities are very different, the intensities will be equal, since—as the particles are not, if we may so speak, more closely packed in one than in the other—the quantities in equal spaces, of both will be equal: and, therefore, the indications of the electrometers will be the same. If, in the second case, the same amount of electricity is supposed to be in each, the quantities will be equal; but, since the particles are twice as near in B, they will exert four times the repulsive force of those in A: the intensity of A's electricity will be four times that of B, and the divergence of the electrometer will be proportionally increased.

FIG. 244.

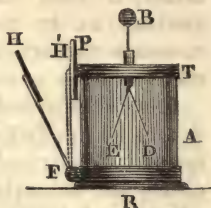


8. *The gold leaf electrometer* consists of a glass cylinder A,

* *Scopeco*, I examine carefully. *Gr.* † *Metreo*, I measure. *Gr.*

fig. 245, having a brass cap T; and standing firmly on a brass base R. A glass tube is inserted in the cap; and within it is fixed a brass wire, carrying at its lower end the slips of gold leaf E and D, and terminated above, by a metallic ball B.—The gold leaf may be conveniently cut between two leaves of the book in which it is sold, by a very clean and sharp razor. It is then easily separated from the pieces of paper: and, while it lies upon one of them, may be attached by the centre, to the end of the wire, if the latter is moistened with gum water—or even simply with the breath. The glass cylinder protects the gold leaf from currents of air; and, as we shall see just now, prevents the electricity from passing to the earth.

FIG. 245.



H, and P, are metallic discs:—P is fixed to the cap T, by a screw; and H may, by means of a joint at F, be brought nearer to, or farther from, P. When it is at H'—near P—it increases very much the *capacity* of the latter for electricity, and, by consequence, causes it to take more than it otherwise would, from any excited body with which it is brought into contact. Removing H, after P has been electrified, diminishes the capacity of the latter, and causes an increased divergence of the gold leaves. The excess of electricity in P, when H is removed, becomes diffused over the cap, and the leaves: and a quantity of that fluid, so small as to be otherwise almost inappreciable, may thus be made to produce very perceptible effects. The discs H, and P, are called the condenser of Volta; their action depends on *induction*, a principle which I shall explain presently.

FIG. 246.

9. The *quadrant electrometer* consists of a stem of ivory, P, fig. 246—which, like the other portions of electrical apparatus, is terminated by a ball, to prevent the electricity from being dissipated, in a way that I shall notice at the proper time. The stem P carries a graduated semicircle D, from the centre of which a thin piece of light wood terminated by a pith ball B is suspended—so as to be movable round it. When the instrument is electrified, the ball is repelled by P, and the arc through which it passes is indicated by the graduation on D.



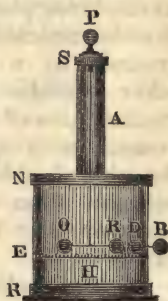
10. The number of degrees through which the index EB is deflected does not indicate the precise amount of repulsion, nor, by consequence, the relative quantity of electricity, accumulated on the electrometer and the bodies with which it is in communication. It is found, by accurate experiment, that electrical attraction and repulsion are “inversely as the square of the

distance." Hence, if the distance between TP and B is doubled, the electrical repulsion being diminished to one-fourth, it will require four times as much electricity to support EB, supposing the effect produced upon it by gravity to be unchanged: which, however, is not the case, as is evident from the principles on which the bent lever balance [mech. 170] is constructed.

11. It is likewise found that, the distance between two electrified bodies being constant, when the quantity of electricity in one body changes, the attraction or repulsion varies as that quantity; when the quantities in both change, the attraction and repulsion vary as their product—but, if they change precisely in the same way, as the square of their sum. In all cases, the repulsion may be represented by the product of the quantities divided by the square of the distance.

12. *The torsion electrometer* was used by Coulomb to prove, experimentally, the laws of electrical attraction and repulsion. It consists of a glass jar, NR, fig. 247, in the brass cap of which is

FIG. 247.



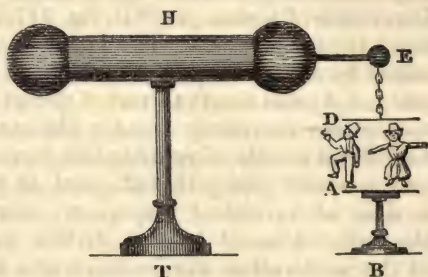
fixed the glass tube A. The latter also is terminated by a brass cap, from which, at P, is suspended, by the single thread of the silkworm or some other extremely slender filament, a small horizontal needle of gum-lac OR, having, at one end a small gilt pith ball, and at the other a disc of varnished paper—to counterpoise the ball. A small hole is drilled in one side of the jar, to allow the insertion of a horizontal wire, terminated at the ends by metallic balls, B and D. The gum-lac needle and filament may be turned round, by means of the knob P.—If, while the apparatus is unelectrified, the pith ball is in contact with the inner knob D, it will, on touching B with an electrified body, become similarly electrified, and will recede from D. The amount to which the needle will be moved round, is very nearly proportional to the repulsive force, and is indicated by the graduated arc E. If OR, and DB, are oppositely electrified, the arc through which the former will move, so as to come into contact with the latter, in opposition to the tendency in the thread, &c., to resist torsion, indicates the amount of attraction.

13. **EXAMPLES OF ATTRACTION, AND REPULSION.**—These effects may be exemplified by rubbing glass, or sealing wax with silk or flannel; and holding it near pieces of paper, cut very small. The paper will first be attracted, and then repelled:—some pieces will adhere, because, as we shall find, their points and edges will give out the electricity to the atmosphere, and, having ceased to be electrified, they will not be repelled with the rest.

14. If we electrify the inside of a tumbler glass, by bringing every part of it, successively, in contact with a metallic substance connected with the electrifying machine—while, at the same time, the hand is held on the outside: then throw into it some pith balls, and invert it over a metallic plate: the pith balls will fly with great rapidity from the glass to the plate, and from the plate to the glass.—They are attracted by the electrified glass; but, after being electrified, are repelled by it, and attracted by the plate, to which they give their electricity; and being then in a *neutral* or *natural* state, are again attracted by the excited glass. Placing the hand, from time to time, on the outside of the tumbler, will increase or renew the effect:—the reason of this, however, would not be intelligible at present.

15. This experiment is capable of being varied in a great many ways. If a metallic disc D, fig. 248, is suspended horizontally from the conductor H—a similar disc being placed under it, and connected with the ground, by a chain or other metallic body—

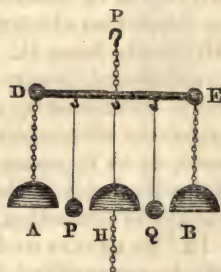
FIG. 248.



small figures of men, &c., formed with paper, or the pith of elder, placed between them, will carry the electricity from one to the other, so as to represent a dance.

16. Two bells, A and B, fig. 249, are suspended with small chains from a rod DE, attached by a wire, &c., to the conductor of an electrifying machine: and a bell H, with two metallic balls P and Q, are hung by silk threads, to DE—the bell H being connected with the earth. When the handle of the electrifying machine is gently turned, the bells A and B, becoming electrified, will attract the balls P and Q, and then repel them. As soon as P and Q are repelled by A and B, they will be attracted by H: and, giving their electricity to it, will return to the natural state, and be again attracted, as before, by A and B. This successive attraction and repulsion causes the bells to continue ringing.

FIG. 249.



When the handle of the electrifying machine is gently turned, the bells A and B, becoming electrified, will attract the balls P and Q, and then repel them. As soon as P and Q are repelled by A and B, they will be attracted by H: and, giving their electricity to it, will return to the natural state, and be again attracted, as before, by A and B. This successive attraction and repulsion causes the bells to continue ringing.

17. A further illustration of the same principle is derived from a grotesque head, covered with long hair. When this is placed

on the conductor of the electrifying machine, and the handle is turned, the hair becoming electrified, bristles up—exhibiting the appearance of great fear.

18. Clouds remain suspended in the atmosphere, probably, from their electrified particles repelling each other.—We shall find, hereafter, that water becomes electrified, during a change from the fluid to the vaporous, or from the vaporous to the fluid state. Forests, mountains, &c., by taking away their electricity, cause the particles constituting the cloud, to unite together in drops, which fall, by their own weight, in the form of rain. A thunder-storm is very frequently accompanied by rain, on account of the electricity, which kept the particles of vapour separated, having been suddenly discharged.

19. **ELECTRICS AND NON-ELECTRICS.**—It was soon found that friction did not excite electricity on all substances. This gave rise to the distinction between *electrics* or substances capable of having electricity produced upon them by friction, and *non-electrics* or substances incapable of being thus excited. Afterwards, however, it was ascertained that all bodies may be electrified, but that, in some cases, the electricity, being transmitted at once to the ground, is not perceptible.

20. **CONDUCTORS AND NON-CONDUCTORS.**—Electricity is conveyed, more or less perfectly, by some substances, and not at all, by others. The former are termed *conductors*, the latter *non-conductors*. Water conducts well, concentrated acids and the metals still better. Highly rarified air is a good conductor; but it is said that electricity is not conveyed by a perfect vacuum. Copper transmits electricity twenty times better than iron: iron four hundred million times better than water: and water several thousand times better than dry stone. The conducting power of water diminishes at the freezing point, and ceases at 13° : neither iron nor alumina, in a finely divided state, have been found to be conductors; and iodine is a conductor, after it has been fused, but not in the form of crystalline plates:—glass and sulphur, on the contrary, reduced to powder, acquire to a certain extent, the power of conducting. Some bodies, in the solid state, are non-conductors of electricity—particularly if its intensity is low. While, however, the capability of transmitting electricity is produced, or increased by the fluidity of *non-metallic* bodies, their power of conducting heat is diminished, or destroyed by it. Some bodies become conductors, by a change of temperature—thus glass, when heated to redness. The conducting power of many substances is due to the moisture they contain:—indeed the deposition of moisture on electrical apparatus, through the hygrometric state of the atmosphere, or from the breath of the spectators, causes,

on this account, a very serious inconvenience to the experimentalist. Though both glass, and the resins are non-conductors, the former is sometimes coated with a varnish, formed by dissolving sealing wax in spirits of wine :—the damp is supposed to be deposited on this varnish less freely than on the glass.

21. A body, between which and the ground a non-conductor is interposed, is said to be *insulated*.—The higher the intensity of the electricity the more imperfect the conducting power which will be sufficient to transmit it ; and the larger the surface of a non-conducting substance, across which it will pass spontaneously. A stool with glass legs called an *insulating stool*, is very useful in electrical experiments.

22. It may be shown, by striking the brass cap of the gold leaf electrometer [8] with a silk handkerchief, that all bodies, when insulated, will exhibit electrical excitement, on being rubbed. The divergence of the gold leaves will prove that brass—a “ non-electric ” [19]—is capable of being excited.

23. We may demonstrate the conducting power of some bodies and the want of it, in others, if we cause the leaves of the electrometer to diverge by touching its brass cap with an electrified substance, and bringing whatever is to be tested in contact with it :—should the leaves collapse, they have lost their electricity, and the body which touched them is a conductor ; if no such effect is perceived, it is a *non-conductor*.

24. The speed with which electricity travels is enormous.—Though a wheel should turn with such velocity as that its spokes are invisible, a flash of electric light enables us to see them perfectly :—because, during the existence of the light, the wheel does not move through a sensible space. Or, if the compartments of a card [opt. 108] painted blue, yellow, &c., is made to revolve, so that the colours disappear, a flash of electric light will make all of them distinctly visible : and the card will, for a moment, seem to stand still. Two sparks will appear to our senses perfectly simultaneous, although the electricity may, between the one and the other, have traversed the longest wire we can use for the experiment.

25. Professor Wheatstone, to whom we are indebted for very important researches on this subject, employed a beautiful means of measuring the velocity of electricity.—He fixed the extremities of an insulated copper wire, half a mile long, in the horizontal diameter of a disc, fixed against the wall of a darkened room. The wire was so arranged, that sparks at the extremities, and centre of it, were seen on the diameter. A small revolving mirror was placed at the distance of about ten feet—its velocity being known by the note produced [pneum. 69] with a tooth, or pin in its axis, which struck against a card. If the three sparks on the disc were visible simultaneously,

they would be reflected in a perfectly straight line, and would vanish, before the mirror had sensibly changed its position; if not, the mirror would revolve, for a small space of time after one had appeared, before the other would be seen—so that the three would form an angle. The deviation of the reflection being known, as also the distance and velocity of the mirror, the time between the consecutive reflections could be ascertained: and this, with the length of the wire, would give the velocity of the electricity.

26. THE TWO ELECTRICITIES.—Bodies which are electrified do not always repel each other. There are two classes of substances of such a character that, if two bodies are electrified with the electricity derived from either class, they will repel each other: but, if one body is electrified with electricity derived from one class, and the other body with electricity derived from the other class, they will attract each other.—Thus a feather electrified by an excited glass rod, will be repelled by the latter, but will be attracted by an excited stick of sealing wax: and, electrified by an excited stick of sealing wax, it will be repelled by the latter, but will be attracted by the excited glass rod.

27. These different species of electrical excitement are always co-existent:—that is, we cannot produce the one without its being accompanied also, by the other. For the feather repelled by the glass tube, or the sealing wax [26], will be attracted by the silk or the flannel which has been used to effect the electrical excitation.

28. When the electricities are of low intensity, it would appear that some bodies, capable of transmitting one of them, are imperfect, or even non-conductors of the other.

29. Positive electricity or that of the excited glass rod, leaves the point of a wire in the form of a pencil or brush: negative or that of the excited sealing wax, in the form of a star.

30. It may be asked, to what these opposite effects should be attributed. This question has been answered differently. Du Fay supposed that the electricity of bodies in a natural state is formed by the union of two elements, the one, that which is produced by exciting glass, and which was called by him *vitreous*,* the other that of resinous substances, such as sealing wax, and termed *resinous* electricity: and that friction merely separates these elements.—Chemistry will hereafter teach us that very inert compounds may consist of most energetic constituents. His announcement of electrical attraction and repulsion was, “that similar electricities repel, but opposite electricities attract each other; and that matter and electricity manifest a mutual attraction.”

* *Vitrum*, glass. *Lat.*

31. Dr. Franklin believed that the two electrical states were produced in bodies, merely by an excess, or a want of the *same* element; and that, when vitreously electrified, according to Du Fay, they have *more*, but when resinously electrified, *less* than in their natural state.—Hence in the former case they were said by him to be *plus*, or *positively*, and the latter *minus*, or *negatively* electrified. According to his idea, “two bodies both plus, or both minus, repel each other: but one plus and the other minus, or one plus or minus and the other in a natural state, attract each other.” His opinion seemed to be the more simple, and was very generally adopted; there are arguments, however, in favour of each.

32. It is difficult to conceive that a mere negation, such as negative electricity is, in the opinion of Dr. Franklin, can cause repulsion. Nor is the reply, that matter when unelectrified repels matter in the same state, quite satisfactory: although undoubtedly, the general law by which matter attracts matter, may hold, only with matter in its ordinary electrical state.

33. Some explain the repulsion of two negatively electrified bodies, by supposing that they do not actually repel each other, but that they are attracted in opposite directions by matter, air for instance, in which an opposite electrical state has been produced on account of their inductive action:—we shall understand presently, what is meant by induction. It seems favourable to the opinion of Du Fay that when electricity is transmitted through a card, or sheets of paper, there is a burr on *each* side—which could scarcely happen, unless something had passed, at the same time, in the two opposite directions. Also, in Professor Wheatstone’s experiment [25], the *middle* one of the three sparks, is seen the last.

34. CIRCUMSTANCES WHICH AFFECT THE NATURE OF THE ELECTRICITY, PRODUCED BY FRICTION.—We cannot, as might at first be supposed, pronounce, before making the experiment, which electricity shall be obtained from a given substance. For the nature of the result depends on the colour, the temperature, and the surface of the body itself, and also on the body with which it is rubbed.—Thus, if two black, or two white ribands are dried, and drawn between cloth or silk, they will repel each other: hence [26], they are similarly electrified. But a black and a white riband, in like circumstances, will attract each other: they are, therefore, oppositely electrified. *Change of colour* has, by consequence, modified the effect.

35. At ordinary temperatures, smooth glass will, with silk or cloth, give vitreous, but at a higher temperature, resinous electricity. Hence the *temperature* of the body rubbed affects the result.

36. Smooth glass, rubbed with silk, will give vitreous, but

rough glass, resinous electricity. The *surface* therefore modifies the effect.

37. Smooth glass will afford vitreous electricity, when rubbed with any substance, except the skin of a cat. White silk is vitreously electrified with black silk, but resinously with the hand, or paper. Hence, the *nature of the rubber* with which the body is excited, must be taken into account.

38. The following are the results of Cavallos's experiments on the subject—

Substances excited.	Kind of electricity.	Material forming the Rubber.
Back of a cat,	Positive, .	Every substance tried.
Smooth glass,	Positive, .	Ditto, except the back of a cat.
Rough glass,	Positive, .	Dry oiled silk, sulphur, metals.
	Negative, .	Woollen cloth, paper, wax, human hand.
Tourmaline,	Positive, .	Amber, a current air.
	Negative, .	Diamond, the human hand.
Hare skin,	Positive, .	Metals, silk, leather, the hand.
	Negative, .	The finer furs.
White silk,	Positive, .	Black silk, metals, &c.
	Negative, .	Paper, hand, hair, &c.
Black silk,	Positive, .	Sealing wax.
	Negative, .	Furs, metals, the hand.
Sealing wax,	Positive, .	Metals.
	Negative, .	Furs, the hand, leather, cloth, paper.
Baked wood,	Positive, .	Silk.
	Negative, .	Flannel.

39. We can easily ascertain the nature of a given electricity, by means of the gold leaf electrometer [8], after causing it to diverge with a known electricity.—If, on *touching* the cap with the excited body to be examined, the divergence of the gold leaves is increased, the electricity to be tested is the *same* as that which was communicated to the electrometer; if the divergence is diminished, or destroyed, it is of a *different* kind. We must take care, however, that the electricity to be examined does not first neutralize that which is on the cap, and afterwards itself cause the leaves to diverge. Also, as we shall find, the effect will depend on whether the excited body is only brought near, or is made actually to touch the cap.

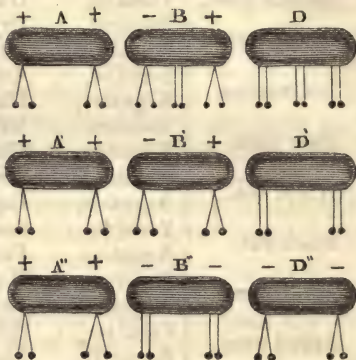
40. INDUCTION.—When an electrified body is placed near one in its natural state, the whole of the latter, if it is connected with the ground, will become oppositely electrified: but, if it is insulated [21], the extremity next the electrified body will be *oppositely*, and that which is farthest from it *similarly* electrified:—this is said to arise from “induction.” It is due to the electricity of the excited body driving away, as far as possible, that which, in the unexcited body, is of the same species as itself.—Induction, therefore, is one of the consequences of the mutual repulsion of electrical particles of the same kind [3].

If the body, upon which the electricity had been induced, remains insulated, equilibrium is restored and the opposite extremities resume the natural state, when the electrified body is removed. But, if a connexion was made with the ground and the insulation was restored, while the electrified body was still present, equilibrium cannot follow:—since the electricity which was driven away cannot return from the ground; and whatever kind happens to be in excess, will diffuse itself over the entire body, as soon as the exciting cause is withdrawn.

41. The effects produced by an excited body on one that is in its natural state, are illustrated

FIG. 250.

by fig. 250. The positively excited state is indicated by + : and the negative by - . In the first place, A is supposed to consist of glass, and to contain positive electricity : B, is a metallic body, negatively electrified, by induction, at the side next A:—it becomes positively electrified at the side farthest from A. If A is removed, B returns to the state in which it was, originally—which will be represented by D.



42. Next, A' is supposed to represent a *metallic* body excited positively: and producing, by induction, negative electricity on the side of B', another metallic body which is next to it:—this renders the farther extremity of B' positive. But since A' is metallic, and therefore a conductor, the reaction of the negative electricity of B' makes the side of it next to B' more positive, by taking some of the positive electricity from its other extremity—which therefore becomes less positive: and the side of A' next B' having become more positive, acts more strongly on B'. This action and reaction proceeds, until the different electricities acquire a maximum intensity—depending on circumstances. D' represents the state of B' if A' is removed.

43. Lastly, A'' is supposed to be an excited metallic body acting on another, B''. If the latter is connected with the ground, &c., and is again insulated, while A'' is present, the whole of it will be negatively electrified:—but the electricity developed being neutralized by the action of that in A'' it will *not be indicated* by the electrometer. When A'' is taken away, the state of B'' will be indicated by D''.

44. Before an electrified body attracts one that is in its natural state, it induces upon it the opposite kind of electricity, by driving away, as far as possible, that which is of the same denomination.

45. Farady, concludes, from his experiments, that the transmission of electricity through conductors is merely a rapid induction, propagated from particle to particle, and destroyed when the exciting cause ceases—while with non-conductors it continues for some time.

46. THE LEYDEN JAR was discovered by accident, at Leyden, from which place it derives its name.—As Cuneus was repeating an experiment of Muschenbroek, a chain happened to be suspended from the conductor of the electrifying machine, and to dip into a phial of water. After the machine had been turned for a while, Cuneus seized the phial with one hand, and attempted to remove the chain with the other; but received a shock, which greatly surprised and frightened him.—His astonishment and fear, however, evidently caused him very much to exaggerate the effects produced. The consequences of this accident were the discovery of the Leyden jar, the principle of which I now proceed to explain.

47. If the central portions of both surfaces of a plate of glass are covered with some metallic substance—tinfoil for instance, and we attempt to electrify one surface, the other also being insulated, that electricity, of the latter surface, which is of the same kind as what we try to accumulate on the former, will repel it. Hence, as the electricity we endeavour to transmit to the plate is alone movable, it will be driven—or rather kept away: and the glass will be electrified, to but a slight extent.

48. If, however, we uninsulate the second surface, the electricity of that surface will have become the most movable, and, therefore, it will pass off—in sparks, if there is a trifling interruption in the conductor which transmits it. Electricity is being constantly accumulated on the conductor of the machine, and on that surface of the plate which is in connexion with it: its repulsive force, therefore, will be sufficient to overcome the electricity on the uninsulated surface—which, by consequence, will be driven away, through the passage that has been opened for it. Such, precisely, is the result we obtain by experiment.

49. The opposite sides of the glass plate are oppositely electrified. For, if a small disc of metal, having an insulating handle, is brought into contact with one of them, and afterwards, with the gold leaf electrometer, and—the electricity it contains being previously removed with the finger—is then applied to the opposite side of the plate, and to the electrometer, the leaves of the latter, which at first diverged, will collapse:—which shows that the electricities, obtained from the different sides, were of opposite kinds [26].

50. Before touching either side of the plate, with the disc, it will sometimes be necessary, previously to uninsulate the opposite:—for the side to be examined may have already lost

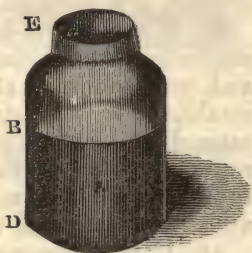
as much electricity as the state of the opposite side will permit : and therefore, without such a precaution, it may not give any more to the disc.

51. As the two sides of the glass plate are oppositely electrified, and the two electricities have a tendency towards each other, we have only to form a conducting communication between them, and equilibrium will be restored—what is called a *discharge* being produced. If the human body forms a portion of the communication or *circuit*, as it is termed, the sensation, termed a *shock*, will be experienced.

52. We may submit any substance to the action of the electricity, by making it form part of the circuit.

53. The Leyden jar, fig. 251, differs in shape only, from the plate of glass. It is a bottle, or jar, having an opening which will allow the interior coating to be put on. Both coatings consist of tin-foil, reaching to within a short distance of the mouth:—the more powerful the electrical apparatus, the more extensive must the uncoated portion be ; or a discharge will take place across it. When the proper kind of jar cannot be obtained, ordinary bottles, containing shot—or even water—instead of the inner coating, may, sometimes be used.

FIG. 251.



54. When a number of jars are united, by forming a communication, with wires or chains, between all their inside, and a similar one between all their outside coatings, the apparatus is called an electrical *battery*. There is no limit to the number of jars, except that the machine will not be able, beyond a certain extent, to supply the dissipation of electricity—arising from points, dust, and other causes, to which I shall presently direct attention.

55. All bodies connected by conductors, as far as electricity is concerned, are to be considered as but one.—Thus, all the inside coatings of a battery act as the inside coating of one large jar ; and all the outside coatings, as one outside coating. The thinner the glass, the more highly it can be charged ; since [10] the inductive action, between the surfaces is greater, because they are nearer :—but it is, then, more likely to be broken by a spontaneous discharge *through* it, a small aperture being formed. It appears, from the experiments of Faraday, that induction is communicated through the jar, from particle to particle :—it depends, therefore, not merely on the thickness, but also on the nature of the insulator.

56. When we discharge a jar, or battery, all the electricity

is not removed: hence, it must, after a short interval, be discharged again. The electricity, which was on the uncoated part of the jar, gradually diffuses itself over the coatings, and constitutes the *residual* charge which, though not considerable, may, unless it is removed—from the surprise it produces by the unexpected shock—cause the operator to injure some of the apparatus.

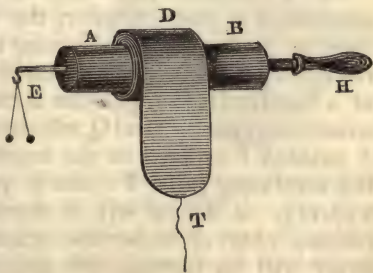
57. DISTRIBUTION OF ELECTRICITY.—The electricity of a Leyden jar is diffused over the surface of the glass, and not on the tinfoil forming the coatings. The latter are required only that we may charge or discharge the entire surfaces at once:—for, without them, since glass is a non-conductor, it would be necessary to touch nearly all the points of the jar, successively. If we charge a jar with movable coatings, the latter having been removed with a glass rod, touched, and replaced, the jar may still be discharged.—Had the electricity been in the coatings, it would evidently have been dissipated, when they were uninsulated.

58. It follows, as a consequence of the mutual repulsion of the particles of electricity, that it can be found only on the *surfaces* of bodies:—for its particles tend to separate as far as possible from each other. The sphere, therefore, is the only figure to which an even coating of electricity can be given. Oblong bodies must have an accumulation at their extremities:—if these extremities are small, or if the surface contains points, the accumulation which results, and the consequent tendency of the electricity to escape, must be very great.

59. This tendency varies as the square of the quantity in a given place. For it is in a ratio compounded of the repulsion of the particles and their number:—but these vary as each other; and, therefore, the tendency to escape varies as the square of either.

60. The effect of expanding the surface, in lessening the intensity of the electricity contained on it, while the quantity remains the same, is well illustrated by the apparatus, fig. 252. A thin lamina of metal is attached, at one end, to a cylinder AB, and coiled upon it. The cylinder is capable of being turned freely on the axis EH—terminated, at one extremity by the insulating handle H: but it is brought back to its former position by a spiral spring, contained within it. A pith

FIG. 252.



ball electrometer is attached at E. If the apparatus is charged with electricity, the pith balls will diverge; but their divergence will be diminished on drawing out the lamina, by means of the silk thread T; and will gradually increase, on allowing the spring within the cylinder, to move the latter round, and again coil up the lamina.

61. It follows from these principles, and it is shown by experiment, that, if a needle is fixed in the conductor of an electrifying machine, it will be almost impossible to produce even the smallest electrical effect; and that, if a point is presented to an excited body, its electricity will imperceptibly, but rapidly, disappear. When either positive or negative electricity is discharged through a point, there passes from the latter a strong current of air, which may be thrown against a flame, or may be made—by means of vanes set in its circumference—to cause the revolution of a light wheel.

The smaller the extremity of a body, the nearer it approaches, in its nature and results, to those of a point.

62. THE ELECTRICAL MACHINE.—Those principles which have been examined, enable us to construct an apparatus capable of generating, accumulating, and discharging electricity in large quantities; and, therefore, to ascertain more perfectly its various properties.

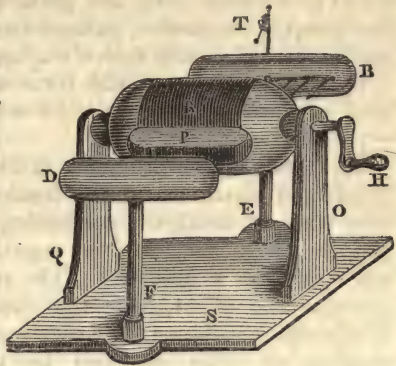
63. However different in form, all such apparatus must be similar in principle, because it must necessarily include the body which is rubbed [13], and that which produces the friction; points, to take the electricity from the excited body [61]; a conductor—either metallic or covered with a metallic substance—to receive and transmit that fluid to the jars [53]; an electrometer [9]; and a means for effecting the discharge.

64. Otto Guericke, of Magdeburg, to whom we are indebted for the air pump [pneum. 19], was the inventor of the electrifying machine, also. It was, originally, a globe of glass, rubbed with the hand; but more convenient forms, and a better rubber were afterwards adopted.

65. *The cylindrical machine* is represented by fig. 253. It consists of a glass cylinder, the ends of which are segments of spheres, having small but strong necks. The latter are cemented, respectively, into caps attached to the spindles on which, by means of a handle H, the cylinder is turned freely but steadily, in the wooden supports O and Q, which are firmly inserted in the stand S. A cushion P is fixed to the *negative conductor* D, supported on the insulating pillar F: and is pressed against the cylinder, by a spring. A flap of silk R, sewed to the edge of the cushion, reaches over, or under the cylinder—according to the way the latter will be turned, and almost touches points, fixed in the *prime, or positive conductor* B—which is supported on an

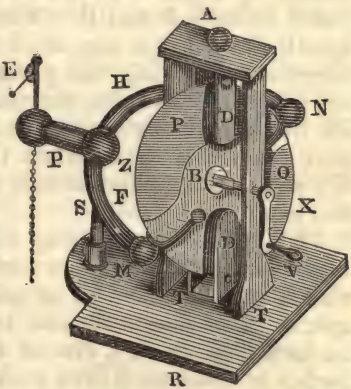
insulating pillar E. The silk flap prevents the electricity from being carried off, by the stratum of air next the cylinder, or by the dust, before it reaches the points. A chain or wire leads from the prime conductor to the interior of the jar, or battery, which is to be charged; and the electrometer T, indicates the relative amount of accumulated electricity. Sometimes the supports, and handle, are insulated: but this is unnecessary, the *ends* of the cylinder being quite sufficient to insulate the electricity developed upon it—particularly as the cushion does not extend along its entire length. The cushion must communicate, by a chain or wire, with the ground—or with the inside of a jar, or battery, which has its outside coatings connected either with the ground, or with the outside of the jar or battery attached to the prime conductor. The interior of the jar or battery connected with the negative conductor, will be negatively electrified; and the two jars, or batteries, will be charged with the same labour, as but one.

FIG. 253.



66. *The plate machine* is represented fig. 254. It consists of a strong circular plate of glass B, having a metallic spindle which passes through, and is firmly attached to it. By means of a handle V, it is turned freely but steadily, the wooden supports T, T, fixed on the stand R. Four cushions D, D, &c.—two on each side—are pressed against the glass, by screwing up balls on the ends of rods, that pass through the slips of wood to which each pair of cushions is fastened. Two pair of silk flaps, each joined, respectively, at their corresponding edges X and Z, prevent the electricity from being dissipated. The conductor HPF, is insulated and supported by the glass pillar S, and has an electrometer at E. Two sets of points, each extending at both sides of the plates, are fixed to the ends of the conductor.

FIG. 254.



67. This kind of machine is very powerful, but it occupies more space, and is more liable to accidents than the cylindrical:—without care, the glass will be broken, on account of the unequal expansion, caused by heat. It is difficult, also, to insulate its rubbers in such a way as to obtain negative electricity.

68. Brown paper would form an excellent, but a perishable kind of machine.—It must be well dried, before it is used for any electrical experiment.

69. The cushion or rubber is filled with horse hair—to render it soft and elastic; and the leather which covers it, is rubbed over with an amalgam containing one part of tin, two of zinc, and six of mercury, melted together, and then triturated with hog's lard, in a mortar. This amalgam is found greatly to increase the effect, from the chemical action which occurs.—Wollaston has shown, by experiments made with amalgams little capable of oxidation, and by the use of atmospheres not containing oxygen, that oxidation is the cause which produces machine electricity. Some experiments performed by Sir H. Davy, were, however, productive of contrary results.

70. *The discharging rod* is an instrument, employed to make, or to complete a communication between the interior and exterior coatings of a jar or battery. In its simplest form, it is merely a bent wire, with two balls at its extremities: without these [61] the electricity would be discharged gradually, instead of suddenly—which is necessary for the production of its most powerful effects. The ordinary discharging rod is represented, fig.

FIG. 255.

255. It consists of curved wires, united by a joint at D, and terminated by balls A and B. The glass handle H, prevents any shock being experienced during the passage of the electricity through the wires.—To obviate all inconvenience, however, from this cause, when the discharge is very powerful, a dry silk handkerchief, &c., is to be interposed between H, and the hand.



71. *The electrophorus of Volta* is a simple kind of electrical machine, which is both convenient and effective for experiments that, like the explosion of gases, do not require more than a spark. The *sole* is formed by soldering a metallic hoop, half an inch high, upon a disc of the same substance, about twelve inches in diameter: then melting equal parts of shell-lac, resin, and Venice turpentine together, and pouring the mixture within the hoop—until it rises a little above its upper edge. A metallic plate, of the same diameter as the disc, having a small knob of brass united by a short wire to its upper surface, is lifted on, or off the sole, by a glass handle which is fixed to its centre.

The resinous cake is excited, by rubbing, or striking it with the skin of a cat; and the metallic plate being then laid on, touches it—however smooth—at only a few points. The electricity derived from this limited contact, is given out in the form of a spark, when a knuckle is applied to the knob; after which the other parts of the excited surface acting on the metallic plate by induction [40], produce upon it the opposite species of electricity. Each time the plate is removed from the resinous cake—having been touched with the finger, &c., while in contact with it—a spark may be taken from the knob. One excitation of the apparatus will, under favorable circumstances, be sufficient for a long time.

72. MECHANICAL EFFECTS OF ELECTRICITY.—The electrical machine enables us to examine the effects produced by considerable quantities of electricity. Some of these effects are due to its *intensity*—or the repulsive force mutually exerted by the particles [7]: others depend on *quantity*: and others require both, to a certain extent. Mechanical effects—or those which produce, modify, or destroy motion—are obtained only from electricity of great intensity: and, hence, they are particularly remarkable in that which is derived from friction. Machine electricity expands conductors and non-conductors—breaking and tearing asunder the latter with great violence. When it is transmitted through conductors, some, but not all, of the effect is due to the heat produced: and they are often permanently expanded in one direction. The passage of electricity through a chain, diminishes its length; and a piece of hard drawn iron wire, ten inches long, and the one-hundredth of an inch in diameter, was found, after fifteen discharges, to have become one inch and one-tenth shorter.

73. If two wires are inserted in a piece of wood, so that their points may be about a quarter of an inch asunder within it, when electricity is transmitted through them, the wood will be broken.

74. If a charge is passed through a capillary tube containing mercury, or water, the tube will be fractured.

75. Electricity sent through a quire of paper, or a card, will perforate it—a burr being perceived, as I have already remarked [33], at both sides. If the card DE, fig. 256, is coloured with vermilion, and blunt wires A and B, are placed one at each side—their points being about half an inch apart, on transmitting electricity through the wires, it will be perforated, opposite to the wire which is connected with the negative side of the battery; and the course of the electricity will be indicated by a black line on the card.

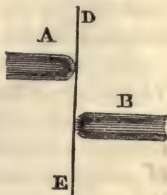


FIG. 256.

76. If some oil is poured into a glass flask, and a wire, bent at right angles near its lower extremity, is inserted in the cork—the point of the wire being within the oil, and in contact with the flask, and the latter being hung from the conductor, by the wire—when the machine is turned, and strong sparks are taken with the knuckle, or a brass ball, from the point which is in contact with the interior of the glass, the electricity will perforate the latter, in passing out to the knuckle or the ball.

77. If the points of wires, forming the circuit, are pressed into a sheet of writing paper, at some small distance from each other, the electricity, in passing along the paper, will tear it. If paper, cut into small pieces, is made a portion of the circuit, a discharge will scatter it, with great violence.

78. *The electrical orrery*, fig. 257, is often used to illustrate the mechanical effects of electricity.

S is supposed to represent the sun; E, the earth; and M, the moon. Points P, P, are fixed horizontally to the wires; and S, M, &c., are so balanced that they are capable of moving freely on H and H.—During an experiment, the wire T is inserted in the upper part of the conductor;

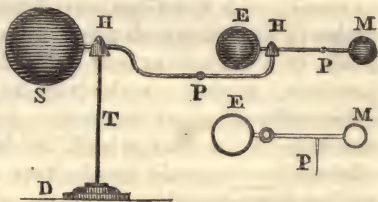
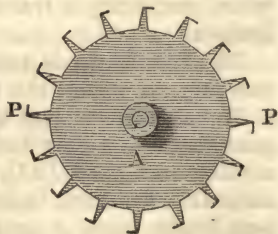


FIG. 257.

the wire T is inserted in the upper part of the conductor; and, when the orrery is not used, in the stand D. T being placed in the conductor, and the machine being turned, the electric fluid escapes from the points P, P; and motion in the opposite direction is produced—on a principle already described [hyd. 128]. E and M revolve round their common centre of gravity; and, at the same time, both of them, along with S, revolve round T.

79. A star A, fig. 258, having points P, P, &c., and a small hollow, in its centre, will, for a similar reason, revolve, if it is placed, instead of the orrery, on the wire T (fig. 257): the latter being inserted in the conductor, while the machine is worked. The motion of the star will be in a direction opposite that towards which the points are turned.

FIG. 258.



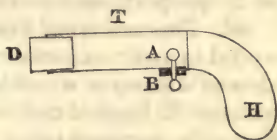
80. **CHEMICAL EFFECTS OF ELECTRICITY.**—These consist in the decom-

position of compound substances, or their formation from the elements which compose them. It may be proved, by a variety of experiments, that electricity will cause combustion, one of the most important examples of chemical action.—A charge passed through a brass knob covered with tow, or cotton, over

which powdered resin has been sprinkled, will set the tow, or cotton on fire. Electricity will inflame alcohol placed in a metallic dish—if its temperature has been slightly raised. It will explode gunpowder; but to prevent the latter from being scattered like the small pieces of paper [77], before it has had time to take fire, it must either be mixed with metallic filings, or part of the circuit must consist of wetted cord—which, not being a good conductor, will, to a certain extent, retard the electricity, and give it time to act.

81. *The electrical pistol*, fig. 259, consists of a handle H, formed of baked wood, that it may be a non-conductor: of a brass tube T, which may be closed by the cork D: and of a metallic ball B, connected with a similar ball A, by a wire passing, for the sake of insulation, through a piece of ivory, firmly fixed in the brass tube. A small quantity of hydrogen gas, and half its bulk of oxygen, being placed in T, the cork

FIG. 259.

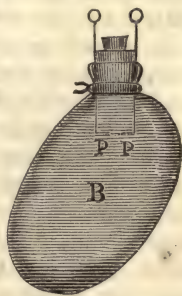


D is inserted tightly in its place: and the forefinger of the hand which grasps H being placed in contact with the brass barrel, the knob B is brought so near the conductor, that, while the machine is turned, a spark may pass to it.—The gases will explode, driving the cork out with great violence, and a loud report. The electricity escapes from the conductor to B: thence, from A, through the gases, to the brass tube: and thence through the hand to the earth.

If oxygen cannot be easily procured, common air—which contains it—will answer very well; but its volume must be much greater than that of the hydrogen, that the oxygen may be in sufficient quantity. The pistol may be conveniently charged, by inverting it, and holding within T, the neck of a flask from which hydrogen is being evolved, until the proper quantity is supposed to have mixed with the air inside of it.

82. This experiment may be made in a different way, and on a larger scale, by filling a bladder B, fig. 260, with the same mixed gases, and suspending it from the ceiling, in a distant part of the room. The circuit is formed by insulated wires, which are carried round the wall, and attached to P, P, which pass through the cork, to which the mouth of the bladder is tied—their points being inside, and at a small distance from each other. On transmitting electricity through the gases, they will explode with a flash of light, and a deafening noise, the bladder

FIG. 260.



being torn to pieces. Such experiments become more effective, when the room is darkened.

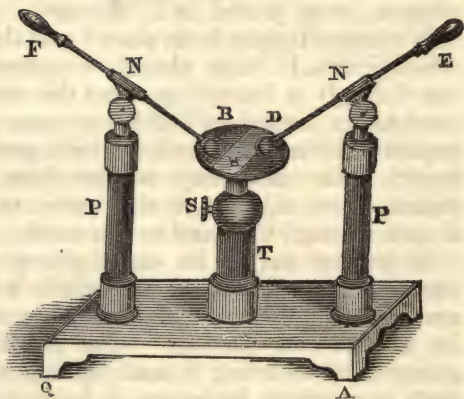
83. Electricity will separate the elements of bodies, as well as combine them.—A current of machine electricity is capable of decomposing water : but, since quantity rather than intensity [7], is required for chemical effects, certain difficulties arise in making this experiment. Dr. Faraday's mode of overcoming them, shall be described, when I speak of the decomposition of water, by galvanism.

84. The blackening of the card [75] was due to the chemical effect which the electricity produced on the vermilion.

85. Electricity causes the evolution of great heat.—If very fine steel wire is made part of the electrical circuit, a quantity of it, proportioned to the power of the battery, will be melted.

86. *The universal discharger*.—This instrument is extremely useful in many experiments of electricity and galvanism. It consists of a stand of wood QA, fig. 261, in which are fixed the glass pillars P, P. Each of the latter is surmounted

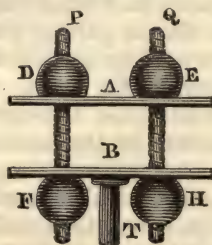
FIG. 261.



by brass joints N, N, which allow rods passing through them, to move freely in every direction. Glass handles F and E are attached to the rods; and also the balls B and D. A small table of baked wood having a piece of ivory H, inserted in its upper surface, is capable of being fixed at

any height in a stand T, by means of the screw S. The pointed extremities of the wires may be exposed, when requisite, by unscrewing the balls B and D. Any thing can be submitted to the action of the electricity, if it is placed on the table, and the circuit is completed by connecting one rod of the discharger with the outside coating of the jars, and the other—with the discharging rod—with the prime conductor.

FIG. 262.



87. The screw press, fig. 262, is often used instead of the upper portion of the table T, fig. 261.—If two small plates of glass, between which some gold leaf is laid, are screwed up tightly between A

and B, a discharge, passed through the gold, will melt it : and some of the metal changed into an oxide, will indelibly stain the glass—which, generally, is broken in pieces. Paper may be tinted in the same way.

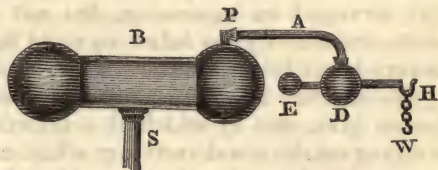
88. PHYSIOLOGICAL EFFECTS OF ELECTRICITY.—When the animal body is made a portion of the electric circuit, a peculiar effect, called a *shock* [51], is experienced:—and if it is sufficiently powerful, the animal dies, or it is more or less injured. Animals killed by electricity, soon putrefy. Electricity is sometimes beneficially applied to medical purposes. It was used even by the ancient physicians, although they were not aware of its nature: for they applied the shocks given by the torpedo—which, Galen tells us, were considered useful in headache, though he could not himself bear testimony to their advantage. We are not, however, to be surprised at this, since the fish with which he made *his* experiments were dead.

89. Electricity is administered in various ways.—If the person, or the part diseased, is extremely sensitive, the operator stands on an insulating stool [21], and, touching the prime conductor, holds a point towards the place where the patient is affected; on which a sensation similar to that caused by a light breeze is experienced:—hence, this is called the *electrical aura*.*

90. If the part, or person is stronger, the operator—or the patient—stands on an insulating stool: and sparks are taken from, or given to the spot affected.

91. If the person is sufficiently robust to bear a shock, the diseased part is made a portion of an electric circuit. The strength of the shock may be regulated by the *self-discharging electrometer*, fig. 263. It consists of a bent glass rod A, ter-

FIG. 263.



minating at one end by a thick brass wire, which may be placed in the upper surface of the conductor B, and at the other by a brass knob D. A rod having a ball E, at one extremity, and at the other a hook H, passes freely through D: and a chain W is attached to H. The knob E may be placed at any required distance from the conductor B: and, when the charge has become strong enough to pass through that distance, the electricity will go from B, which is in connexion with the interior coating of the electrified jar, to E—through the intermediate air: thence, by H, along the chain W and the person who is to receive the shock, to the outer coating. The distance between the conductor and E being once adjusted, the charge

* From *aura*, a breeze. *Lat.*

cannot be either greater or less than what will give the electricity just power enough to pass the space between them. If the charge is found to be too strong, E may be pushed in towards B: and the reverse, if it is too weak.

92. Electricity, when transmitted through plants, destroys them:—some persons, however, consider them benefited by it, when it is drawn from the air to the ground in which they grow, by pointed rods fixed among them.

93. MAGNETIC EFFECTS OF ELECTRICITY.—It was long known that needles of steel, through which the electric discharge is made, are sometimes magnetized, and at others, are demagnetized—or have their poles reversed. Also, the mariner's compass has been affected by the aurora borealis, which we shall find to be an electrical phenomenon.

94. ELECTRIC LIGHT.—This is never perceived, except when there are interruptions in the conductors, along which the electricity is transmitted. It is produced in various ways.—Long and narrow strips of tinfoil are fastened by gum, &c., on plates of glass: and interruptions are made in the foil, at short intervals, so as to express by them, words, or any kind of figures:—when electricity is transmitted, the words &c., will be represented by sparks at the interruptions, in the same way as stars, &c., are represented with small lamps, during an illumination—but far more brilliantly.

95. If a plate of glass is covered with a thick varnish, on which pins' heads or very small pieces of wire are strewed, a portion of the opposite surface of the plate of glass being covered with tinfoil, when it is charged, or discharged, in the ordinary way [51], the electricity will traverse the side covered with the pins' heads, in zigzag lines of varied appearance, and great splendour.

96. When electricity is transmitted through spangles of tinfoil, arranged in succession, but not quite in contact, on the inner surface of glass tubes, so as to form spirals, &c., the effect is very beautiful.

97. Electric light is modified by the nature and shape of the bodies from, and by which it is taken.—Thus small balls give a zigzag spark: wood and ivory afford a crimson; silvered leather a green; and powdered charcoal a yellow light. Similar modifications arise, on changing the body by which the spark is drawn.

98. Electric light is affected, also, by the medium through which it passes.—If an egg, an orange, a piece of loaf sugar, or of chalk, is placed between the knobs of the universal discharger [86], it will be lighted up with great brilliancy, on discharging the battery. The sugar and chalk sometimes become *phosphorescent*—that is, will emit light for a while, after the cause which illuminated them has ceased to act.

99. If a thumb is placed upon the ends of the wires belonging to the universal discharger—the knobs being removed,

and the points being separated a little from each other—the electric fluid will render the bone and veins visible. Since it prefers the best conductors, it will pass from one wire to the other, *under the thumb*: and, therefore, no shock will be felt. Experiments on electric light are to be made, if possible, in a darkened room.

100. **ATMOSPHERIC ELECTRICITY.**—The atmosphere is generally found to be electrified.—This is proved by shooting into the air, an arrow connected with an electrometer. Professor Saussure and his companions being caught in a thunder cloud, when ascending the Alps, were astonished to find their bodies so filled with electricity, that they emitted spontaneous sparks, with a crackling noise: and they experienced the same sensations as are felt by those artificially electrified. In fine weather, the atmosphere is positively electrified, and the intensity increases as we ascend: its electric state varies in unsteady weather: and, sometimes it is neither positive nor negative.

101. Franklin first suggested the best proof of what, indeed, was suspected before his time—that lightning and electricity are identical. Richman, a Russian Philosopher, unfortunately lost his life, in researches, on this subject. All the ordinary experiments of electricity have been made with that obtained from the clouds, by means of a kite, or a tall pointed rod. The bodies of animals killed by lightning—as well as by electricity [88]—fall rapidly into putrefaction.

102. *The aurora borealis* is undoubtedly an electrical effect, and arises from discharges which take place in the higher regions, where the air is greatly rarified [pneum. 37]. It is likely, from the calculations of Cavendish, that it occurs at the distance of about seventy-one English miles from the surface of the earth. The density of the atmosphere, at such a height, being only the $\frac{1}{146567}$ th part of what it is, at the surface, it is far more rarified than the air within the exhausted receiver [pneum. 33]. D'Alton has estimated the height of the aurora at 100 miles. We may imitate this phenomenon exceedingly well, by exhausting the air from a long and wide tube of glass—within which there is, at one end, a point, and at the other, a knob of brass. When a spark is taken from the conductor, by a large knob which is at one extremity of the glass tube, the latter is filled with a beautifully soft white light.

When the mercury of the barometer is made to oscillate for an inch or two in the dark, flashes of electric light are perceived in the torricellian vacuum [pneum. 31] on account of the friction of the metal against the glass.

103. *Falling Stars* are, most probably, discharges which occur nearer to the earth, where the air is denser, and where, by consequence [20 and 21], the electricity must be accumulated in larger quantities, before it can overcome the force which prevents its transmission.

104. The passage of electric sparks through atmospheric air, is accompanied by an odour, which is like that of phosphorus, and is perceived, also, near an excited electrifying machine. It has been ascribed to a peculiar substance called *ozone*, about which I shall have occasion again to speak.

105. PROTECTION FROM LIGHTNING.—The protection, both of ourselves and buildings from the terrible effects of lightning, is a matter of great importance. In these countries, the damage produced by it is comparatively insignificant:—but while witnessing a terrific thunder-storm at the foot of the Alps, on the Italian side, and another in Venice, I felt that we have, here, only an imperfect idea of this tremendous power.

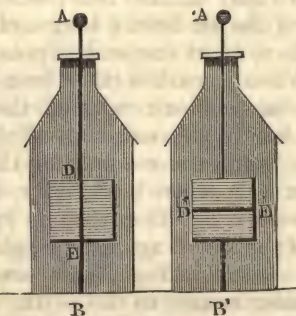
106. There are, in thunder-storms, two sources of danger:—one arising from the *direct shock*, in which the electricity passes, through us, to, or from the clouds: the other, from the *return shock*. The latter is a consequence of the electricity induced upon us [40] by the proximity of a highly electrified cloud, which—being discharged by another cloud, or the earth—suddenly becomes unelectrified. This return shock is felt, also, when we discharge a battery of much extent, particularly if we use, for the purpose, only a wire [70]:—the electricity, as it passes, disturbs the equilibrium of that which is in the hand. It is not certain, however, that the return shock can be productive of very serious consequences.

107. In thunder-storms, we must, obviously, avoid every thing calculated to attract the lightning, such as tall trees, &c.; also good conductors, such as sheets of water, &c.

108. Buildings are sometimes protected by *paratonnerres*,* or rods elevated far above their highest pinnacles. They are pointed at their extremities [61], and gilt—that their sharpness may be preserved as long as possible. They should not communicate with the walls, by any conducting substance: nor ought they be so thin, as will expose them to the danger of fusion; and they should sink into the earth, at a distance from the building, or—which is better—should communicate with a sheet of water.

109. The effect produced by lightning on steeples, &c., particularly, if the stones are cramped with metal—and thus form *interrupted* conductors—may be well illustrated by the “thunder house,” fig. 264, which is a small model of the gable end of a building. A wire AB, attached to it, represents the paratonnerre: and a portion of it is fixed to a movable piece of

FIG. 264.



* *Para*, against, *Gr.*; and *tonnerre*, thunder, *Fr.*

wood DE—so that there may be formed an uninterrupted conductor, as represented by AB, or an interrupted one, A'B'. In the former case, when a charge is sent through the wire, the piece of wood remains in its place, although quite loose; but in the latter, it is thrown off with great violence.

110. Some of the heat, caused by lightning, is probably produced by violent compression of the air, during the passage of the electric fluid.

111. The distance, at which lightning has occurred, may be easily ascertained, if we mark the number of seconds which have elapsed between the flash and the thunder, and multiply it by 1,089, the space [pneum. 59] through which sound travels, in a second. Our pulse will, on such an occasion, supply a tolerably accurate means of measuring the time, if the period between two pulsations is considered as a second.

112. It is not necessary to remark that the distance at which the last discharge has occurred, is but little security against the next—which may take place immediately over us. Gay Lussac has found that a flash of lightning sometimes darts more than three miles, at once, in a straight line.

CHAPTER VIII.

GALVANISM.

History of Galvanism, 1.—Nature of Galvanism, 5.—Connexion between Galvanism and Electricity, 10.—Apparatus for producing Galvanic Electricity, 14.—Various kinds of Galvanic Battery, 23.—Effects of Galvanism, 52.—Chemical effects, 53.—The Electrotpe Process, 65.—Physiological, &c., effects, 110.—Other sources of Electricity, 117.

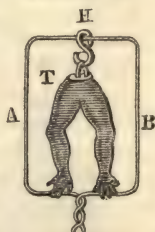
1. HISTORY OF GALVANISM.—Several facts, attributable to galvanic agency, have long been known. Thus, that porter, and some other fluids, have a different taste, according as the vessel, out of which they are drank, is silver, pewter, or glass, &c. : also, that soldered joints tarnish rapidly, &c. As a science, however, galvanism has been known only for a short period. The first great fact upon which it is founded, was discovered by accident.—Galvani, professor of anatomy at Bologna, found about the year 1790, that a small quantity of machine electricity, sent through the nerves of a frog, recently killed, produced a violent agitation of the muscles. He perceived, on pursuing the train of experiments suggested by this fact—which, indeed, was first remarked by his wife—that frogs, when hung to iron rails by the crural nerves, with hooks of copper, were violently convulsed, as often as the wind blew the muscles against the rails.

2. A frog may be prepared for illustration of this fact, by leaving only a small portion of the spine adhering to the crural nerves : and suspending the latter to an iron wire AB, fig. 265, by a copper hook H.—When the limbs are made to touch the wire, convulsive movements will occur.

3. It may be further shown that some animals are affected with a small quantity of galvanic electricity, by placing a leech on a plate of silver—a crown piece, for instance—which rests on a plate of copper, somewhat larger. As often as the animal touches both metals, it will convulsively shrink within one of them. The shocks received by it in this way, generally cause it to die.

4. If a piece of zinc is placed under, and a piece of silver over the tongue, a peculiar taste, and sometimes, if the eyes are shut, a flash of light will be perceived, when their edges are

FIG. 265.



brought together. This taste arises from some of the saliva being decomposed.

5. NATURE OF GALVANISM.—Galvani, by repeating his experiments with the frog [1], was led to the conclusion that the muscles and nerves are in opposite electrical states; and that the metals restore equilibrium, by effecting a species of discharge.

6. But Volta, another celebrated experimentalist, and contributor to the science, who shared with Galvani the honour of giving it a name—for it is called also *Voltaism*—found that one metal will not, in all cases, be sufficient. It ought, however, to be so, if only a conductor were required. He attributed the effect produced to contact of the metals: showed that it is not necessary to connect a muscle and a nerve, since they act merely as conductors between the metals: and demonstrated, by means of his condenser [elect. 8], that contact between different metals produces electrical excitement.

7. An opinion, more correct, however, than that either of Galvani, or of Volta, assigns the galvanic effect to chemical action. And we have reason to believe that the one is always accompanied by the other:—even in ordinary combustion, the gases which pass off, and the substance which remains behind, are found oppositely electrified. Chemical action, indeed, whether it has reference to the decomposition, or to the production of chemical compounds, depends on the electrical state of the substances concerned.—For, Sir H. Davy has shown that we can suspend, or accelerate the solution of a metal, according as we connect it with the one pole of the galvanic battery, or with the other. And Dr. Faraday has demonstrated that electricity itself is merely a new form of chemical affinity, exerted through a longer space—so that electricity and chemical affinity may even be made to assist each other.

8. The electric column of De Luc—which shall be described when I speak of the various forms of galvanic battery—does not prove any thing contradictory to this opinion: since though its energy lasted for a long, it did not last for an indefinite time; and there is every reason to believe that its excitation is accompanied by some chemical action—however small.

9. Volta's opinion was, that those fluids, which serve as the best conductors between the metals, are productive of the most energetic effect.—But we are to attribute this superiority of result, not to the goodness of their conducting power, but to the greatness of their action upon one of the metals employed. That it is not due to the *conducting power* of the fluid, will be evident, if we use plates of copper and tin; for with ammonia, which acts most on the copper, the tin will be positively electrified; but, with an acid solution, which acts most on the tin, the

copper will be positively electrified.—In a word, the metal most affected will become negative, compared with the other, whatever may be the conducting power of the fluid. Faraday remarks, that chemical action, and not contact, must be the cause of galvanic effect, since a spark is produced before contact is made.

10. CONNEXION BETWEEN GALVANISM AND ELECTRICITY.—It was soon perceived that galvanism and electricity, if not identical, are at least intimately connected; for the electrometer was found to be affected by either pole of the galvanic battery. But the purely electrical effect is greatest, when the galvanic energy is least—that is, when the fluid used as the exciting agent is pure water, or a weak acid solution; in these cases, however, the battery must be very considerable. It is possible, also, to charge a number of electric jars by a galvanic battery, their inside coatings being connected with one of its terminal plates—called *poles*—and their outside coatings with the other. The charge is communicated instantaneously; but it is very weak.

11. The following may be considered as the principal points of difference, between machine and galvanic electricity.—The former is always produced by friction [elect. 19], but is increased in amount by chemical action—which alone, is the cause of the latter. The former is of high intensity, but is small in quantity; the latter has but little intensity, but is considerable in quantity. Electrical excitation, indicated by the electrometer, manifests itself only when the circuit is open—that is, when the two oppositely electrified portions of the apparatus are not connected: and hence, the electricity of the machine has been termed *statical*,* its effects being perceived, although it is in a state of rest. On the contrary, galvanism never exhibits any energy, but when the circuit is closed: and hence, it is termed *dynamical*,† being perceptible only when it is in a state of motion. Rarifying the air, causes the electricity surrounded by it, to be carried off: but does not affect a wire connected with the pole of a galvanic battery.—Dr. Faraday, however, proved that rarified air transmits even galvanic electricity: since he decomposed water, and deflected the galvanometer, when the heated air between the charcoal points—gradually separated—formed a part of the galvanic circuit.

12. Although electricity and galvanism are, as I have said, most probably modifications of the same principle: it is impossible to say where one commences, and the other terminates. Electricity may be made to resemble galvanism, by placing a small quantity of it upon a comparatively large surface—which diminishes its intensity; or by placing a comparatively large

* *Statos*, standing. Gr. † *Dunamis*, force. Gr.

quantity on a small surface—which is tantamount to increasing its quantity. And galvanism may be made to resemble electricity, by increasing its intensity—a considerable number of elements, termed “circles,” being employed. We may have some idea of the enormous difference in quantity, between these two modifications of electricity, if we suppose, as Faraday believes and has indeed shown, that, to decompose a drop of water, requires as much electricity, as would produce a flash of lightning.—Yet the decomposition of a drop of water may be effected by galvanism on a very small scale.

13. From what has been said [elect. 21], it can easily be anticipated that galvanism, being of such low intensity, must require far better conductors than machine electricity; and that it will be able to pass across a much smaller space of any substance which does not possess the power of conduction.

14. APPARATUS FOR PRODUCING GALVANIC ELECTRICITY.—Galvanism may be obtained from a single *circle*: that is, by the union of any three bodies, two of which exert a mutual action, and the third increases the effect, by its inductive power. The three bodies constituting the galvanic element or *circle*, may be either two fluids and a solid; or, what is better, two solids and a fluid:—two metals and a fluid are generally used. One kind of metal and a fluid may be made to suffice; but then, the single metal is, in reality, tantamount to two different ones: since its different parts must have a different density, so as to be differently acted on by the fluid—which is equivalent to their being of different species.

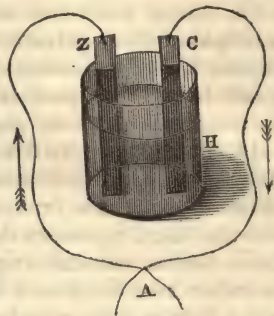
15. *Galvanic batteries*.—Strictly speaking, a “galvanic battery” should be a combination of galvanic circles, as an electrical battery is generally, if not always, considered to be a combination [elect. 54] of electrical jars. It is customary, however, to call any apparatus intended for the production of galvanism, by this name:—under this term, therefore, is included even a single galvanic circle, particularly if it is capable of producing a considerable effect.

16. I shall first explain the action of a single circle.—If a plate of pure zinc or, when this is not to be had, a plate of zinc amalgamated with mercury, is immersed in dilute sulphuric acid, the latter does not act upon it, until a plate of copper, platinum, &c., is immersed in the same fluid:—nor even then, until the two plates are brought into contact. It is to be remarked, that this contact may be effected *outside* the fluid: and it will be sufficient that the connexion is made by a wire. If the zinc is impure, the dilute acid acts upon it at once: and hydrogen gas is given off from it, until contact is made with the copper, &c., or until the two metals are connected by a wire—after which, it is given off from the copper, and the quantity of gas evolved is augmented.

That metal which is acted upon by the fluid, becomes negative, the other, positive : and the electricity flows from the positive to the negative metal—directly, when they are placed in contact, but more circuitously, when the communication between them, or, as it is termed, the *circuit*, is formed by a wire, &c. Whatever constitutes part of the circuit, is of course [elect. 52] exposed to the action of the electricity which traverses it.

17. The effect of a galvanic circle is, ordinarily, attributed to the electricity flowing from the zinc Z, fig. 266, through the fluid, to the copper C, and thence along the wire,

FIG. 266.

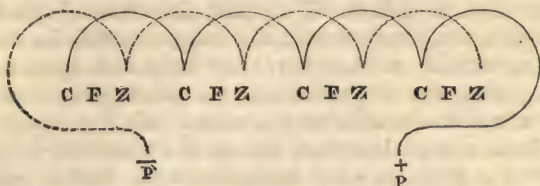


back again to the zinc.—But this is not a satisfactory explanation ; since it assumes that the electricity is at the same time, both drawn *towards*, and driven *from*, the zinc :—for, while the tendency of the latter to acquire electricity, causes it to use, for the purpose, the first conductor that is presented, it is supposed also, to force the very same kind of electricity away, through the fluid, an imperfect conductor. It is far more probable, that the electricity of the zinc enters into combination, so as actually to constitute a part of the new substance produced :—the zinc thus becomes negative, and, acting inductively on the copper, makes it positive ; the copper reacting on the zinc, makes it more strongly negative—that is, causes it more freely to part with positive electricity, one of the elements without which the new chemical body cannot exist. The copper, in becoming positive, takes electricity from as many particles of hydrogen, as correspond with the particles of oxygen entering into combination : the electrical states of the copper and hydrogen are then such as cause them to form a kind of unstable compound—which is easily decomposed, by the negative zinc taking away electricity, one of its elements. This gives rise to the evolution of hydrogen. These effects following each other, in rapid succession, would constitute galvanic action.

18. In a single circle, the intensity is little, or not at all, affected by the size of the plates. If intensity is required, a number of circles must be used :—but they are to be arranged in a peculiar way. To understand this, let us suppose that there are four circles : let the zinc be indicated by Z ; the copper by C ; and the interposed fluid by F. Unconnected in any way, the galvanic elements will be represented by CFZ, CFZ, CFZ, and CFZ. But, connected with wires, represented by the curved lines, fig. 267, they form a single circle, the zinc and copper plates of

which, are four times as large as one of the zinc, or copper, plates which compose it :—for any number of bodies, connected

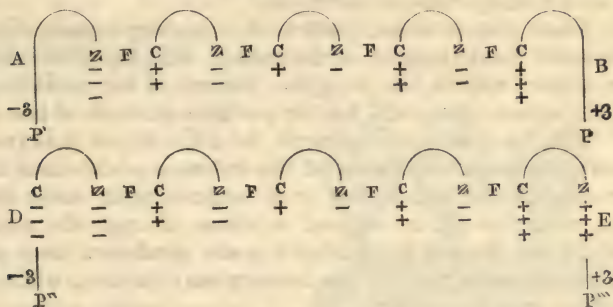
FIG. 267.



by conductors, are, so far as electricity is concerned, to be considered as but one [elect. 55]. All the copper plates, therefore, form but one copper plate; and all the zinc plates, likewise, but one zinc plate:—there is, by consequence, but one circle.

19. The plates may be connected, also, as represented by AB, fig. 268—the zinc of one circle being united with the copper of the

FIG. 268.



next. Each circle has an individual action, which is increased by the inductive effect of that which is next to it.—The middle copper and zinc are, respectively, plus and minus. The zinc, next the copper of the middle circle, if affected only by its own copper, would be, simply, minus; but, being acted upon, to an equal extent, by the induction of the next plate, it becomes doubly minus—which may be represented by two negative signs; and the copper in contact with it becomes doubly plus—which may be represented by two positive signs. This copper, by itself, would make the zinc next to it minus; but, having been excited by the inductive action of a doubly negative zinc, it will cause the state of that zinc to be trebly negative—indicated by three negative signs, or -3 . The electrical conditions of all the plates may be explained in the same way:—and hence, when circles are connected in this manner, the inductive influence of the neighbouring plates must always be added to their own.

The different parts of a galvanic battery are found, by experiment, to have the intensities thus pointed out by theory.

The middle zinc and copper, after a little consideration, will be found, on account of the action of the neighbouring plates, to be more highly electrified than I have shown in the diagram. But, as [elect. 43] equal amounts of positive and negative electricity connected, if I may so speak, by mutual induction, neutralize each other, they have not been taken into account. Also, the electricities of the other plates are more or less neutralized in a similar way: and it is only the *excess* of effect, arising from unequal action, due to the numbers of circles at each side of a given one not being the same, that is perceptible. It follows, that the electricity obtained from such a combination, is derived only from the outer plates.—Hence, increasing the size of the plates, affects the quantity but little, and makes no alteration in the intensity.

20. When the battery is arranged for intensity, the plates must evidently follow each other, in the same order. Without this, they will, to a greater or less extent, neutralize each other's effects, by counter currents.

21. When the extreme plates of a battery are double—as represented in the second arrangement, DE, fig. 268—the extreme copper, will be the negative, instead of the positive pole, and the extreme zinc, will be the positive, instead of the negative. This, however, will present no difficulty, if it is remembered that the electrical state of the extreme plates then arises, not from galvanic action, but from contact with other plates. Unless, therefore, it is noticed whether or not, the extreme plates are in contact with others, some confusion may arise: since, the positive pole of one battery may be zinc, while, that of another may be copper.

22. The fact that, when two metals are immersed in a fluid, only the most oxidizable is dissolved, suggested to Sir H. Davy a means of saving the copper bottoms of ships, from the destructive effects of sea water.—He found that a very small quantity of zinc would preserve many square feet of copper. But an injurious result, which he did not anticipate, rendered this principle inapplicable: for the vessels were retarded by shell fish and marine plants, which adhere to the copper thus protected, and which had been kept away, it is probable, by the oxychloride of copper produced by the action of the sea water.

23. VARIOUS KINDS OF GALVANIC BATTERY.—All galvanic batteries, however different in appearance, are but applications of the fact, that three bodies will constitute a source of galvanic electricity, and that their elements may be united as already described [18 and 19].

24. *The calorimotor*.—This, the simplest form of battery, is merely a pair of plates of different metals, and some dilute acid. Such an arrangement, from its capability of producing heat, has

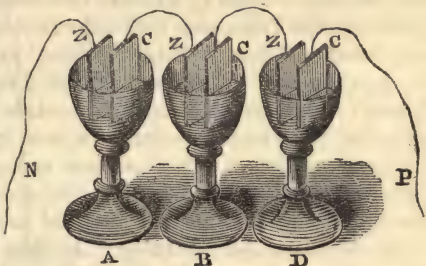
been termed a "calorimotor."* A very powerful battery of this kind, was formed of a large plate of zinc, and another of copper, rolled up together—but not in contact—and let down into a vessel of dilute acid. Contact between the plates, which must be most carefully avoided, may be prevented in a variety of ways:—among others, by the interposition of cloth, &c. The copper itself is sometimes made to form a cell for the fluid.

25. When pure zinc cannot be obtained—that of commerce is always more or less impure—we may amalgamate it [16], even when soiled, by immersing it in a solution of corrosive sublimate, particularly if a little hydrochloric acid is added; or by rubbing dilute sulphuric acid and mercury upon it, with a piece of tow, &c.

26. Various kinds of fluids, termed "charges," have been suggested, for the production of galvanic action.—When there are only a single zinc and a single copper plate, one in fifty, sulphuric acid, and one in a hundred, nitric acid, answer extremely well. We shall find, however, that the nature of the charge depends very much on the kind of battery used.

27. *The Couronne de tasses*,† is one of the simplest kinds of compound battery; and was invented by Volta. It consists of any number of glass cups A, B, and D, fig. 269, containing dilute acid, in which are immersed zinc and copper plates—connected together.

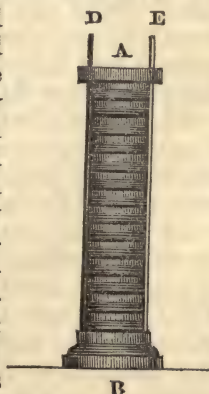
FIG. 269.



Wires P and N, attached to the terminal plates, are very often called the *poles* [10] of a battery.

FIG. 270.

28. *Volta's pile, or column*, fig. 270, is formed with discs of zinc, copper, and cloth, wetted with dilute acid, and built up in the same order. They are retained in their places by glass rods, D, E, &c., fixed in discs of wood A, and B—the former being at the top, and the latter at the bottom of the column. A shock may be taken with this apparatus, by grasping in each hand, a silver spoon, previously wetted with a solution of common salt—which, being a good conductor, renders the contact of the hands with the spoons more perfect: and then applying one spoon to the upper, and the other to the lower plate. As the body is



* *Calor*, heat; and *motor*, a mover. *Lat.*

† *Crown*, or circle of cups. *Fr.*

part of the circuit, a shock is felt, the violence of which depends on the number of circles.

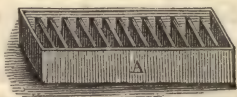
29. When this apparatus is of any extent, it is troublesome to build it up; and, since the discs of cloth retain but little of the fluid—particularly the lower ones, which are pressed by a considerable weight—its action soon ceases.

30. *The electric column of De Luc* [8], contains no fluid. It is composed of a great number of circles, consisting of silver leaf, paper, and very thin zinc—cut in the shape of small discs, and placed in the same order [20] within a glass tube. The electricity generated, is sufficient to keep bells [elect. 16] connected with its poles, ringing for years. The effect of this instrument must be due to oxidation;—for if the paper is quite dry, there will be no action.

31. *Cruikshank's battery* consists of zinc and copper plates soldered in pairs, at the upper edges: and fixed water tight, with cement which is a kind of coarse sealing wax, in the grooves of a baked wood trough A, fig. 271—so as to form cells for the fluid.

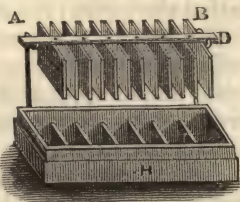
Several inconveniences attend the use of this battery:—among others, the fluid is liable to leak from one cell into another: zinc—reduced to the metallic state, by the hydrogen evolved from the decomposed water—is deposited on the copper: the cells are cleaned with difficulty: and the metals are acted upon, during the intervals between experiments, and while the battery is being charged—which, when there are many troughs, united by wires connecting their terminal plates, occupies a considerable time. The last inconvenience is remedied in the next form of apparatus.

FIG. 271.



32. *Wedgewood's battery*.—In this, the plates are fastened to a bar of baked wood D, fig. 272, so that, when not actually in use, they may be lifted out of the cells of the porcelain trough H, and placed over it on the supports A and B:—the fluid trickles from the plates, into the cells beneath.

FIG. 272.



33. Dr. Wollaston suggested a considerable improvement in this battery—the use of copper, doubled round each plate of zinc, so that the latter should expose two surfaces to its action.

34. *Daniel's battery*—a section of which is seen, fig. 273—is a modification of one invented by Bequerel. It consists of a cylinder of copper A: inside of that is placed a waterproof membrane, which is generally the gullet of an ox tied at its lower extremity: and within the membrane, is a rod of zinc Z. The apparatus is first charged, by nearly filling the membrane with dilute sulphuric acid, and the space between the membrane and the copper

cell, with a solution of blue vitriol; crystals of the latter, also, are placed on a small grating, attached to D—a short copper tube, to which the upper extremity of the membrane is fastened with a cord. The oxide of zinc is kept from being deposited on the copper [31] by the interposition of the membrane: the sulphate of copper on the grating, is gradually dissolved and decomposed, giving fresh acid to the zinc, for which it has a stronger affinity than for the copper, and liberating oxide of copper, which is immediately reduced to the metallic state, by the hydrogen evolved from the decomposed water.—Possibly the latter may give oxygen,

FIG. 273.



at once, to the zinc, and thus render the decomposition of water unnecessary. The reduced copper is deposited on the interior of the copper cell: and, being clean, it produces no injurious consequences. In ordinary batteries, the escape of hydrogen is very inconvenient, not only from the odour by which it is accompanied, but on account of its preventing contact between the fluid and metal, and also its causing zinc to be deposited on the copper:—when the latter occurs, not only is a portion of the surface rendered useless, but counter currents are produced, which, to a greater or less extent, neutralize each other, and thus diminish the galvanic effect.

35. The membrane, which is easily destroyed, has been very conveniently replaced by a cell either of plaster of Paris, of unglazed porcelain—termed “biscuit,” or of “porous ware.”

36. The crystals of sulphate of copper are put in the *upper* portion of the apparatus, because that part is exhausted first: and its greater specific gravity would cause the stronger part of the solution to continue at the bottom.

37. *Groves' battery*.—The plates of this battery are zinc and platinum. The former is immersed in dilute sulphuric acid, which, along with some nitric acid intended to commence the action, is contained in a porous cell; and the latter in strong nitric acid, which is outside of the porous ware. The hydrogen disengaged, takes oxygen from some of the nitric acid, nitrous acid, which remains dissolved, being formed.

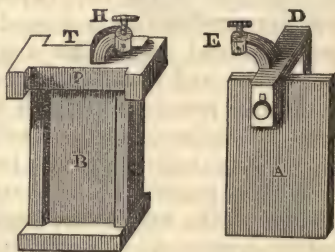
In some cases, the platinum battery is excited by strong nitric acid only, and no porous cell is used. This arrangement answers extremely well if powerful action for short periods is required—as, for example, when gunpowder is to be exploded by a small quantity of fine platinum wire ignited within it. An instrument for this purpose, that has been constructed, consists of twelve small amalgamated zinc cylinders which, by pressure with the hand, are simultaneously immersed in cylindrical glasses, sunk into a small block of slate, and lined with platinum.

The platinum cells thus formed, contain the nitric acid: and the connexions are made by pieces of platinum which are brought into contact by the descent of the zinc, and are so arranged that the zinc of one cell is connected with the platinum of the next [19]. When the wires leading from the battery to the gunpowder are very long, the twelve circles are necessary:—but as many of them as are not required, in any given experiment, may be kept out of action. The zinc cylinders are all lifted out of the fluid at once by a spring: and, the upper surface of the slate block, being carefully ground, may be covered with a ground slab of the same substance: so that the apparatus which is very portable, may be carried about ready charged, without inconvenience.

38. *Smee's battery*.—In this battery, platinized silver is used instead of platinum [37]. The silver is platinized—that is, covered with platinum in a finely divided state—by a process, to be described in treating of the *electrotype*. The *points* of the platinum powder greatly facilitate the evolution of the hydrogen.

39. A thin plate of platinized silver is stretched in a frame of wood P, fig. 274, covered with

FIG. 274.



sealing wax varnish. The plates of amalgamated zinc A, &c., are fixed at each side of the platinized silver, in grooves made for the purpose in the wooden frame; and are kept in their places by a cramp of brass D, and a binding screw. With moderate care, this battery lasts a long time: but the fluid employed must be reasonably free from foreign substances—particularly from copper: and the platinized silver should not be allowed to come in contact with that metal. When the platinized silver and the amalgamated zinc are connected by a conductor, the hydrogen is given off with a hissing noise, and a velocity proportioned to the strength of the battery, and the goodness of the connexion.

40. Amalgamating the zinc will be of no use, if the sulphuric acid contains any nitric acid—which is known to be the case, by its destroying the blue colour of sulphate of indigo.

41. *Bunsen's battery*.—The battery of Chevalier Bunsen is formed by placing a cylinder of zinc, along with dilute sulphuric acid, in a porous cell; and, outside the latter, a cylinder of coke—rendered dense by the mode of its manufacture. Coke obtained from the gas works would answer well, but that it is not easy to give it a proper form; nor, without breaking it, to make the necessary connexions.

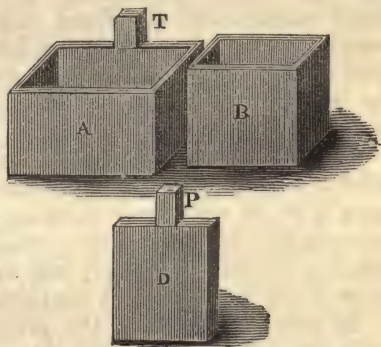
42. *Callan's battery*.—The Reverend Professor Callan, of

Maynooth College, was led to conclude, from experiments made by him on the subject, that platinized lead is superior to platinum, as an element of the nitric acid battery; and that cast iron—which has the advantage of not requiring to be platinized—is fully equal to it.

43. The Maynooth battery consists of a cast-iron cell, represented by A, fig. 275: and,

FIG. 275.

within this, of a porous cell B, somewhat greater in height, but smaller in other respects, particularly in width, that—without removing the cast iron too far from the amalgamated zinc plate D, which is to be placed within B—there may be sufficient space for the fluid, also. If there is room for about a wine glass full—each lateral surface of the zinc being equal to ten or twelve square inches—the



battery will work for nearly three hours, with undiminished power. The apparatus is charged, by pouring into the cast-iron cell a mixture containing equal parts, by measure, of strong nitric acid and oil of vitriol: and, filling the porous cell with a mixture composed of one part, sulphuric acid, and eight, or nine, water. When ten or more cells are employed, the exciting fluid will produce nitrous fumes and boil over, if the mixture does not contain at least one-fourth of its bulk nitric acid: and, as the time during which the action continues depends on the nitric acid, it will, sometimes, be proper to use so much as three-fourths of that fluid. These fumes are given off, also, when the battery begins to be exhausted—which does not, however, occur for two or three hours.

44. The connexions are made, by soldering narrow slips of sheet copper to the cast-iron cells at T, and uniting them, by means of binding screws and other slips of copper, with each other—when quantity is required [18]; or, with the zinc plates respectively next to them in succession—when intensity [19] is to be obtained.

45. If the cells are large they are sufficiently steady, particularly if of a cylindrical form—but, then, they allow only one surface of the zinc to act [33]. If small, they are prevented from being accidentally overturned, and are kept in their proper positions, by being arranged in the grooves of a wooden frame:—any number of these frames may, obviously, be combined together.

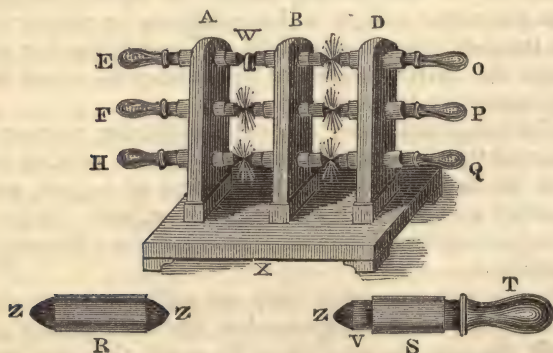
46. It has been found by Dr. Callan, that the intensity of the cast-iron battery is twice as great as that of other batteries, having the same number of circles; that it is nearly as powerful and a half as a Groves' battery, containing the same surface of zinc: and fifteen times as powerful as a Wollaston battery, of equal extent. The apparatus used in some of Dr. Callan's experiments, was equivalent to a Groves' battery containing 140 square feet of platinum—whilst the largest, known to have been constructed, contained only twenty square feet; and it was equivalent to a Wollaston battery, containing 1,400 square feet of zinc—whilst the largest ever employed, which was made by order of Napoleon for the Polytechnic School, contained only 600 square feet.

47. When this battery was arranged for intensity [19] the effects were enormous: and it was necessary for those employed near it to be extremely cautious—particularly as its electricity was capable of passing over considerable surfaces of non-conducting bodies. A turkey was killed by it instantaneously, the craw being burst, and its contents thrown about the room.

Its power, in burning the different metals, was very great: and the effects produced were most brilliant.—When coke points were used, the light was so intense as to make all others appear extinguished. The coke best adapted, for such purposes, is that which is found in a dense and compact mass, attached to the interior of the retort in which coal gas is manufactured.

48. In producing the light, a stand, like that represented, fig. 276, is found very convenient. It consists of a wooden base X,

FIG. 276.



on which are fixed two pillars of brass A and D, and one of wood B. In these, were inserted, small brass tubes containing coke holders—the exterior ones being movable, with great facility, by means of the handles, E, O, &c. There may if requisite,

be more than three pillars. Each pair of coke points being brought very near to each other but not in contact, small bent wires, like that at W, are hung over them, so as to form a conducting communication between them. And, when A and D are connected, respectively, with the poles of the battery, according to the energy of the latter, more or less of these wires will be burned off—the coke points under them being instantaneously lighted. When only two points are used, and they are gradually separated, as far as is possible—without extinguishing the light—the luminous arch produced is very beautiful: but the light does not seem to be so intense as when the points are nearer.

49. The distance to which the points may be separated depends on the power of the battery; and is greatest *in vacuo*. The number of wires that will be burned off, in the *same* horizontal line depends on the “intensity” of the electricity:—four pair of points were ignited, with a battery consisting of 275 cells, arranged as so many circles [19]. The number of *different* lines in which points will be ignited, depends on the “quantity.” It is difficult, however, so to make the arrangements, that the currents will be properly divided between the lines, and not all pass through one of them.

50. The coke is not burned, but transferred from the positive to the negative pole. Hence, the brilliancy of the electric light is not at all diminished, *in vacuo*, or in gases which contain no oxygen; and but little, when it is produced under water. It answers better than the oxy-hydrogen lime light [opt. 56] for the microscope; and is well adapted for photographic processes [opt. 140]. Dr. Callan found that, on bringing a magnet near it, a kind of snapping noise was heard—which was produced also, when a wire of iron, &c., was used, instead of one coke point. The light, in these cases, was gradually extinguished, but assumed, previously, the form of an angle, the vertex of which was turned upwards. The effect was, however, probably due to the conducting power of the intermediate air being diminished, on account of the increased density, produced by cooling. The electric light is put out by a strong wind.

51. The properties of a cast-iron battery must not be attributed to the *passiveness* which iron has been discovered to possess, in certain circumstances:—since wrought iron will not answer for the cells.

52. EFFECTS OF GALVANISM.—Galvanism being more remarkable for “quantity” than “intensity,” we are to expect from it, principally, the results due to the former [elect. 83]:—and its *mechanical effects* are insignificant.

53. CHEMICAL EFFECTS OF GALVANISM.—The production of chemical effect requires not only quantity, but a certain degree

of intensity, also. Hence a single circle, containing even enormous plates does not decompose water : and a vast number of circles consisting of small plates, is nearly as incapable of this effect, although, when charged with that fluid they powerfully affect the electrometer.—The body to be acted upon must not be a non-conductor, or it will be unable to transmit the galvanic electricity : hence, potash is decomposed, only when moistened. On the other hand, if the body is an extremely good conductor, the electricity will pass through it with too great facility.

54. A galvanic battery evolves great heat:—for, by means of it, we can fuse, and even inflame the metals. When gold is burned, the light is white; when silver, green; when copper, red.

55. Galvanism separates, and reunites elements. Thus, it will decompose water, or combine the gases of which it consists. The former is effected, by placing wires of platinum, which are connected with the poles of a battery, in a small quantity of water : oxygen will then escape at the one, and hydrogen at the other wire. The decomposition is greatly facilitated, by acidulating the water with sulphuric acid. If the wires were made of an oxidizable substance, the oxygen would not be evolved, but would enter into combination with one of them. We can explode the gases, and thus produce water, by the heat which the battery itself may be made to evolve.

56. Dr. Callan decomposes water with his battery [43], to obtain the gases required by the oxyhydrogen microscope. For this purpose, fifty cast-iron cells, four inches high, four and a half wide, and one inch broad, will form a very convenient apparatus ; and will afford a quantity of gas sufficient to maintain the light required by the high magnifying powers:—twelve cells, six inches square, supply what is necessary for those which are low.

The cells and zinc plates are to be connected in such a manner as to form but three circles [19], a number great enough to produce the maximum quantity of mixed gases :—the lower the intensity, the longer the battery will work. The water, to be decomposed, is to be acidulated with one part in ten of sulphuric acid : and platinum plates, connected with the poles of the battery, are to be immersed in it. These plates should be parallel, as near each other as possible, and equal in surface to at least one-sixth of all the zinc plates acting as a single one—in each of the three circles. No metal but the platinum ought to come in contact with the acidulated water.

57. Instead of the platinum, which is very expensive, Dr. Callan employed with, at least, an equally good result, plates of sheet iron—those connected with each pole of the battery being united, respectively, by wires H and O, fig. 277. In this

arrangement, the two surfaces of all the iron plates, except the outer ones, are in action. To bring them as near as possible to each other, without the danger of their coming into contact, pieces of gutta percha are wrapped round small portions of their upper and lower edges; and pieces of porous ware are inserted here and there, between them.

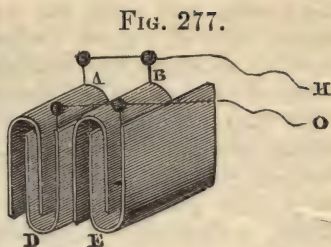


FIG. 277.

58. When iron plates are used, instead of acidulated water, we must employ a solution of caustic potash, the strength of which should be such as not to cause too great foaming—which inconvenience, however, will be prevented, by making the vessel, containing the potash solution, sufficiently large to leave enough space over the fluid.

59. To prevent danger, from the explosion of the mixed gases, contrivances, which I shall describe hereafter, may be used. Or they may be collected separately, by an apparatus, which Dr. Callan found to answer extremely well.—It consists of a small tub, or other wooden vessel the interior of which is represented, fig. 278, divided internally by D, a plate of porous ware cemented water and air tight into it



FIG. 278.

—each compartment being closed at the top by a semicircular segment of wood. Two perfectly distinct cells are thus formed: and the tubes E and F, convey the gases from them to a single tube P, on which the jet is to be screwed. Wires H and O, leading from the battery and passing through the segments, are attached within to the sheet iron decomposing plates.—The porous ware diaphragm must not be cemented with any varnish resembling sealing wax, in its composition, since it would be acted upon by the potash: nor can any such be used, in closing the apertures through which the wires H and O enter the cells, as the heat, produced by the passage of the electric fluid, would melt it with great rapidity:—plaster of Paris will answer very well for the purpose. The wires should be, at least, a quarter of an inch in diameter.

60. If one pair of iron plates does not contain a surface large enough, several such vessels may be combined. Or the same vessel may have several porous diaphragms: and the alternate cells, which will then afford the same species of gas, may all be connected, in some convenient way, with common tubes leading to where the light is required.

61. It has been stated that the quantity of water decomposed, is proportional to the amount of electricity which passes through it:—but, Dr. Callan infers from his experiments, that

this is true, only when the intensity is constant, and does not exceed that of twelve circles. Faraday has found that the quantity of electricity required to unite, is the same as that required to separate the elements of a body.

62. Compounds, the elements of which have the strongest affinity, are most easily decomposed by the galvanic battery. Oxygen, chlorine, and the acids, go to what is usually termed the positive pole, and are, therefore, said to be *electro-negative*; metals, inflammable substances, and the oxides, go to the negative, and are, therefore, said to be *electro-positive*.

63. This fact has given rise to the division of substances into electro-positive, and electro-negative. But the arrangement is of little value; since the pole at which a given element shall be found, depends on what is associated with it:—for it may be positive in one combination, and negative in another. Besides, a compound cannot be decomposed by galvanism [53], unless it is a conductor; a single element has no tendency to go to either pole: and, lastly, if a substance consists of two elements, it will not be decomposed, unless it is a compound which contains an atom of each.—Hence, the galvanic battery will decompose hydrochloric acid, which consists of an atom of chlorine and an atom of hydrogen: but not perchloride of tin, which contains two atoms of the chlorine and but one of the tin. Decomposition, however, may occur by secondary action. Thus, when galvanic electricity is transmitted through nitric acid, water is decomposed by the current: and nitric acid by the evolved oxygen—water and nitrous acid being the results.

64. We may very conveniently illustrate the chemical action of the galvanic battery, by placing a solution of common salt, rendered violet by tincture of litmus, in two separate glasses, and—having connected them with moistened cotton—putting the wire communicating with one pole of the battery in one glass, and that communicating with the other pole in the other glass. The elements will be found to cross each other, and pass through the cotton: that portion of the fluid in which the positive wire [21] is immersed will become red—and thus show the presence of an acid: while that in which the negative wire is immersed, will become blue—and thus show the presence of an alkali. Sulphate of potash will give sulphuric acid, in the positive glass: and potash, in the negative. On changing the wires, respectively, from one glass to the other, the reddened fluid will become blue—on account of then receiving the alkali: and the blue fluid will become red—from then receiving the acid. If the wires from the battery are immersed in solutions of nitrate of silver, metallic silver will be found at one of them. Nitrate of copper, treated in the same way, will give metallic copper.

65. THE ELECTROTYPE PROCESS is one of the most important

applications of the chemical action, exerted by the galvanic battery. The copper deposited on the interior of the copper cell in Daniel's battery [34] gave rise to the discovery of this process—which has been gradually brought to great perfection. The copies produced by it are so accurate, that, when its details are properly attended to, the minutest lines in the original are visible on their surfaces, however thick they may be—appearing as hollows at one side, and as corresponding prominences at the other. Hence, it is well adapted for copying medals, &c., multiplying engraved copper-plates, and a vast variety of other purposes.—The plates used by the Ordnance Survey, in printing their maps, were obtained in this way. Copper deposited on the originals, form the “matrixes,” and copper deposited on the matrixes form fac-similes of the originals—which may thus be multiplied to any extent, at little more expense than the cost of the copper: and, whenever the plate becomes deteriorated, a new one may be used. This must greatly advance the art of the engraver, since he is better paid, even at a lower price for each impression, on account of the greater number sold: and, on the other hand, the public is benefited, because the impressions are, not only of a superior character, but are all equally good.

66. When a medal, &c., is to be copied by the electrotype process, moulds are to be formed, and the metal is to be deposited in them. These moulds may be of various substances. Sometimes *fusible metal* is employed:—this may consist of eight parts by weight of bismuth, three of tin, and five of lead: they should be melted together in a clean iron ladle, just long enough to secure complete liquefaction; then poured in drops on a slab of stone, or marble; afterwards, remelted, when the ladle has been cleaned, and poured out as before. The refusion will be advantageously repeated even a third time. This mixture melts at a very low temperature. When used, it is to be poured on a slab, and the medal—quite cold—is to be dropped upon it, from the height of a few inches.

67. Another fusible metal, often used—particularly on the Continent, contains eight parts of bismuth, four of tin, five of lead, and one of antimony; these should be melted several times, as in the preparation of the other mixture. To obtain a mould, from this composition, the medal is to be fitted to the end of a wooden handle, so that a portion of its thickness will project. Some of the metal is then to be poured on oiled cartridge paper, fixed in a box—the sides of which prevent it, when liquid, from flowing away; and it is to be kept stirred with a card, until, being on the point of crystallizing, it assumes a pasty appearance. The medal is then to be struck gently on the solidifying mass:—or, if it is large, it may be dropped down, from a small height.

68. A copper wire is next to be attached to the edge of the

mould. This is effected, by cleaning its extremity, and holding the part a little above it, in the flame of a candle, &c. : on touching what has been cleaned, with a bit of resin, and pressing it against the mould, they will immediately unite.

Copies, in fusible metal, may sometimes be conveniently obtained from a mould, which is itself formed of that substance.

69. The wire, where it is to be immersed, and the mould, wherever metal is not to be deposited upon it, must be coated with sealing wax dissolved in spirits of wine—which will answer in all cases, as a protecting varnish, except when the solution of a cyanide is employed, and then wax, or pitch, must be used.

70. If the mould is to be of wax, the latter, in a liquid state, is to be poured upon the medal, &c.—previously coated, to a slight extent, with olive oil, and heated : a slip of pasteboard will prevent any from flowing about. The wax having been allowed to cool very gradually for some hours, the medals, &c., are to be carefully removed. A mixture of wax and flake white makes an excellent mould.

71. When plaster casts are to be copied, before the wax is poured on them, they must be placed in *hot* water—which should not reach so high, as to cover the parts on which metal is afterwards to be deposited. If in removing the plaster, any of it adheres to the wax, it may be separated, by touching it with sulphuric acid—which, absorbing moisture gradually from the atmosphere, will break it down, so that it may easily be taken away, with a camel's hair pencil and cold water.

72. The wax being a non-conductor, it must be coated wherever the metal is intended to be deposited, with black lead—that which is used for polishing stoves will do for the purpose. The wax having been first breathed upon, the black lead should be applied with a soft brush ; and the coating may be considered complete, when the surface exhibits a fine black polish. To form a connexion with the battery, a clean copper wire must be fixed to the mould, and black lead be put on the place of junction.

73. If the object to be copied is large, *guiding wires* are to be used. They consist of small wires, connected with the larger one from the battery, and touching, with their extremities, different parts of the mould, but particularly its deep recesses. These wires cause the metal to cover the surface all over in a short time ; after which they may be removed.

74. When the moulds are of sealing wax, the black lead will adhere readily, if they are previously covered with a slight coating of spirits of wine, or are exposed to the vapour of ether.

75. Flowers, insects, &c., may be coated with a conducting substance, by dipping them in a weak solution of nitrate of silver. and—while they are moist—exposing them, under a tumbler

glass, to the vapour of phosphorus, dissolved in alcohol, and placed in a little hot sand. Sulphurous acid may be used instead of the vapour of phosphorus.

76. Plaster moulds are to be saturated with wax, or tallow; and, when cold, are to be coated with black lead.

77. Objects in high relief, may be copied in elastic moulds—formed of a mixture, containing three parts treacle and twelve parts glue, carefully melted.

78. Medals, &c., may be copied by pressing them into *gutta percha*—softened in water having a temperature of between 150° and 160° : and objects in plaster, with *gutta percha* macerated in coal naphtha, and rendered plastic in warm water.

79. The battery to be used in the electrotype process, consists of a *generating cell*—which is merely a constant battery [34, &c.]; or of both a *generating*, and a *decomposing cell*. When only a generating cell is employed, the matrix—which is either a metal, or is coated with a good conductor, as above described—takes the place of the copper of the battery [34].—Fig. 279 represents an arrangement of this kind.

D is a porcelain, or glass vessel; B, one of biscuit, or porous ware inside of D; A, a rod of amalgamated zinc having a binding screw connecting it with the wire attached to H—the model, &c, which is to be coated with copper, and is suspended within D. Dilute sulphuric acid being poured into B, and a solution of sulphate of copper into D, metallic copper will, at once, be deposited on H. The sulphate of copper solution must contain as much of that salt as it can dissolve:—if it is not of uniform strength, the stronger portion will remain at the bottom [36]: and the metallic deposit will be of irregular thickness. Some crystals kept on a shelf in the upper part of B, will prevent this. If the zinc is too large, compared with what is to be copied, the deposit will be compact and brittle; or it will be a dull red, a violet, or even a black powder.

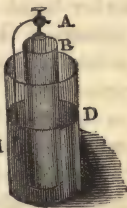
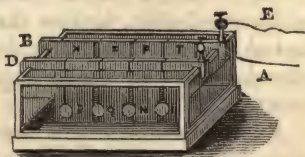


FIG. 279.

80. But it is most convenient, particularly with large objects, to use the other arrangement. Its *generating cell* may be a constant battery, which consists of amalgamated zinc and platinized silver plates, with sulphuric acid [39]. And its *decomposing cell*, fig. 280, may be a glass, or other vessel—formed of a non-conductor—containing a solution of sulphate of copper. Brass rods D and B are placed across the top:—the former is connected with E, a wire

FIG. 280.



the former is connected with E, a wire

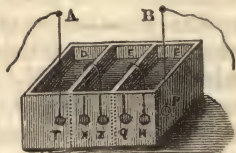
leading to the zinc of the generating cell, and the moulds which are to receive the deposit are hung over it: the latter is connected with A, leading to the platinized silver plates, and some pieces of sheet copper—which are as near the moulds as is possible, without touching them—are hung over it.

81. The copper solution in the decomposing cell is decomposed, and its copper is deposited on the moulds. But it takes copper from the plates, hung upon B:—which, therefore, is gradually dissolved; and, by means of it, the copper solution continues of the same strength.

82. The time required for depositing a certain thickness of copper, depends on the temperature of the solution of sulphate of copper—which, if kept boiling, would cause the deposit to proceed with great rapidity: cold, on the contrary, makes the deposition almost to cease.

83. A single battery may be connected, economically, with a series of decomposing cells: and the apparatus used may be of varnished wood, or one of the porcelain troughs, belonging to the Wedgewood ware battery [32]. Such an arrangement is represented, fig. 281. D, E, and F, are

FIG. 281.



water-tight cells: a plate of copper P, immersed in the fluid of one outer cell, is united by B, with the copper of the generating cell; T, one of the moulds, on which the deposit is to be made, is immersed in the fluid of the other outer cell, and connected by A, with the zinc of the generating cell: other moulds are connected, respectively, with plates of copper, by wires hung over the divisions of the trough. Metal is deposited on each mould, the copper plates connected with it being gradually dissolved [81]—which keeps up the strength of the solution of sulphate of copper, with which all the cells are filled. With such an arrangement, a generating cell sufficient, in other circumstances, for only one decomposing cell, will be quite enough for six, or even more.

84. When the mould is large—to render the deposit even—it ought to be placed horizontally, at the bottom of the decomposing cell, with the copper plate over and parallel to it; and the solution should be agitated constantly—if possible, by a steam-engine, &c.

85. When a fusible metal mould is used, if it is put into the copper solution, before the battery is ready to work, it will be acted upon by the fluid: but if the process is managed properly, the deposit will be so rapid, that the mould will not even be wetted.

86. If the battery is too powerful, or the copper plate of the decomposing cell is too large—compared with the object to be

copied, or if the copper solution is too weak, hydrogen will be liberated along with the copper: and the deposit will be a dark powder.—When the battery is too strong, the plates may be raised a little out of the fluid, or they may be separated to a greater distance, or the connexion with the generating cell may be made with thinner wire.

87. If either the generating cell, or the copper plate in the decomposing cell is too small, or if the copper solution is too strong, the deposit will be brittle.—In weakening the solution we diminish its conducting power; but this may be remedied, by adding to it glauber salt, caustic potash, or caustic soda, until the substance which separates from the fluid, is no longer dissolved again by it.

88. When a coating of black lead is used, except there are guiding wires [73], the copper diffuses itself very slowly over the surface—which causes the battery to be, at first, relatively too strong: and therefore the deposit is brittle, at the place where the conducting wire is in contact with the coating. This inconvenience is prevented by, at first, using a wire, instead of a plate of copper, in the decomposing cell, and immersing it deeper by degrees.

89. When plating or gilding is to be effected, it is necessary to clean the article, on which the gold or silver is to be deposited, by scouring with emery paper, pumice stone, &c. Any oxide upon it, may be removed by a mixture of hydrochloric acid and chalk, &c.; and any grease by the solution of an alkali:—it is, finally, to be well washed with water.

90. Whenever it is intended to separate the metal to be deposited, an exceedingly slight film of oxide is useful; and in such cases, it is proper even to allow time for the film of air, which may have been driven off by heat, when soldering, &c., to return.

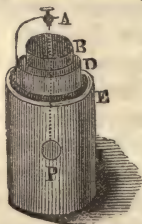
91. Sometimes the surface is amalgamated with mercury, to make the gold or silver adhere to it more perfectly;—and if it is then burnished, *polished* silver or gold will be deposited.

92. The solution from which silver is to be deposited, may be obtained by dissolving pure silver in just enough of nitric acid and water, and throwing into it some solution of cyanide of potassium, until no more white powder falls down.—This white powder is cyanide of silver: and is to be separated from the liquid, well washed with water, and then thrown into a solution of cyanide of potassium—by which it will be dissolved. The resulting fluid is to be placed in the decomposing cell, instead of the solution of sulphate of copper, used in the processes hitherto described: and a plate of silver is to be substituted for the plate of copper:—silver, instead of copper, will then be deposited.

93. In gilding, the liquid employed, may consist of quarter of an ounce of oxide of gold, dissolved in a solution containing two ounces of cyanide of potassium to a pint of distilled water: and a plate of gold is to be immersed in it, instead of a plate of either copper [80], or silver [92].—The works of a watch have been gilt, without stopping it.

94. We may plate or gild, with a single cell, by an arrangement represented, fig. 282. The gold or silver solution is put into a porous cell B, which is placed in dilute sulphuric acid, contained in a porcelain vessel E. A cylinder of zinc D, which surrounds B, is immersed along with it, in the dilute acid. The object to be plated, or gilt, is connected with the zinc, by the wire A, and immersed in the fluid contained in B:—it supplies the place of the copper, platinum, &c., of the ordinary battery.

FIG. 282.



95. If the silver or gold solution is too weak, or if the zinc is too large—compared with the object to be plated or gilt—hydrogen will be evolved, and oxide deposited: which may be known by black lines being perceived. Hence, the sulphuric acid must be very dilute, and oxide of silver, or gold—as the case may be—must occasionally be added to the respective solutions. Since the use of a decomposing cell prevents the necessity of adding oxide, it is, probably, on the whole, cheaper and more convenient to employ one. The coating of precious metal, if required, can be rendered bright, by burnishing; but in some instances the dull colour of the silver, or gold deposit is to be preferred.

Excellent daguerreotype plates [opt. 122] are formed, by the electrotype process.

96. Silver may be platinized [38], by adding a small quantity of chloride of platinum, to acidulated water; then immersing in it a sheet of platinum, connected with the copper, or corresponding element of the generating cell: and—very near to, and parallel with the platinum—the plate to be platinized, connected with the zinc of the generating cell. A deposit of platinum, as a dark powder, will be rapidly formed.

97. If platinized silver gauze is used, instead of a platinized silver plate, in the galvanic battery [39], all the metallic elements of the circle may be brought much nearer to each other, without the free escape of the evolved hydrogen being prevented.—For this purpose, *electro-lace* may be formed, by saturating ordinary lace with wax, removing the superfluous part, while hot, by pressure between blotting paper, coating it with black lead, depositing copper on it, in the usual way, then plating, and finally, platinizing it.

98. Iron may be tinned, by using oxide of tin dissolved in a solution of potash, or of cream of tartar; and it may be covered with zinc, by employing a solution containing one pound of sulphate of zinc, to a gallon of water. Lead may be deposited from oxide of lead, dissolved in potash. Bronzing may be effected, by using a solution containing cyanide of copper and oxide of tin, dissolved in cyanide of potassium.—In ordinary circumstances, the metals will be separated from their solutions, in a regular series. Oxides also may be deposited, by the electrotype process.

99. Daguerreotype plates [opt. 137] are etched with hydrochloric acid, diluted with half its weight of water. The plate to be operated upon, is to be connected with the platinum, &c., of a generating cell: and a platinized platinum plate lying parallel to, and one-fifth of an inch from it, with the other metallic element of the generating cell.—One-fifth of an inch distance allows the sufficiently free escape of the hydrogen, from the platinized platinum. The plates of the generating cell should be of the same size as those of the decomposing cell—of which the daguerreotype plate, varnished on its back and edges, is one. When the etching is finished, the plate is to be rinsed with distilled water: and, if its silver coating is homogeneous, the oxychloride of silver deposited upon it will exhibit a beautiful sienna coloured drawing. This oxychloride, which has been formed by decomposition of both water and hydrochloric acid, is to be dissolved by a weak solution of ammonia—the surface being rubbed with soft cotton; after which, the plate is to be immersed in distilled water, and then dried. It will afford, when printed from, a positive picture—not inverted, as that on the daguerreotype plate itself.

100. It is unfortunate, that—so delicate is the daguerreotype picture—if the etching is continued long enough to give a good impression on paper, some of the fine lines will run into each other. If, on the other hand, the etching is not continued so long, the printer, in cleaning the plate, will destroy it: and, besides, the particles of ink being larger than its details, will, by consequence, be incapable of expressing them.

101. These difficulties are, to a certain extent, overcome by M. Fizeau's process. In it, the plate is immersed in a mixture containing nitric, nitrous, and hydrochloric acid—which corrodes the dark or silver portions [opt. 139]. The chloride of silver, thus formed, being taken away by ammonia, the plate is again immersed—this produces more of the chloride, which is to be similarly removed. The same process is repeated several times. Linseed oil is then rubbed on the plate, and wiped off from the prominent parts. The latter being gilt by the battery [93], the hollows—after they have been freed from

the oil, by means of caustic potash—are to be deepened, by immersing the plate in nitric acid, which will not act on the gilded prominences. Since the plate, if used for printing, would soon wear out, fac-similes are taken from it, in copper [81]. As these faithfully copy the minutest details [65], they produce fine impressions; and when at all impaired, may be reproduced, with great facility.

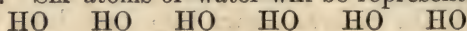
102. If copper is deposited on a daguerreotype plate, a beautiful copy will be obtained:—for, though its colour is homogeneous, the uneven surface of the metal [opt. 182] will so reflect the light, as to render the portrait, &c., perfectly distinct.—Thus we may, by the electrotype, multiply copies of a good daguerreotype.

103. Kobell, of Munich, has applied the electrotype process to the production of pictures.—The designs are painted on a silvered copper plate, with coke, or ochre, rubbed up with a solution of wax in oil of turpentine, the bright lights being left quite free from colour. When the painting is finished, it is washed over with finely pulverized graphite; and being then placed in an electrotype apparatus, copper is deposited upon it. The result is a plate in which all the lights are smooth, and the shadows more or less deeply marked; and which, if treated like the ordinary copper plate, will give impressions similar to Indian ink drawings. This method has been further improved by Thayer, of Vienna.

104. Galvanism appears to be an important agent in the formation of crystals; and its effect, in this case, seems to depend, not on the greatness, but on the long-continued action of the current.—The crystallization of some of the hard substances was found by M. Bequerel, to require years of voltaic action.

105. The chemical properties of the galvanic circle have been applied to the useful purpose of detecting poisons, in suspected fluids. When a drop of the latter is placed on platinum, and a bit of zinc is applied—minute quantities of acid being, in some instances previously added—the poisonous metal will appear on the platinum. If a small quantity of a liquid containing corrosive sublimate, is dropped on gold, when the latter is touched with the point of a penknife, metallic mercury will be perceived.

106. Decomposition, as effected by the galvanic battery, has been variously explained—that of water, for example, by some, as follows. An atom of water contains an atom of oxygen and an atom of hydrogen:—let O represent oxygen, one of its elements, and H, hydrogen, the other. Let N be a wire connected with the negative, and P, a wire connected with the positive pole of the battery. Six atoms of water will be represented by



And these, under the influence of galvanic action, will become—
 N——H OH OH OH OH OH O——P.

The atom next N gives H or hydrogen; and the atom next P, O, or oxygen. The O belonging to the H, that went to N, goes to the H next it—which gives its O to the next H; and so on, through the entire line of particles—in which, however numerous, the oxygen and hydrogen sufficient to form only one atom of water are given off. The atoms set free, belong to the extreme atoms of water: and all the elements except two are again combined—though in a different way.

107. Wollaston has proved by experiment, and Faraday has still further demonstrated the fact, that machine electricity may be made to resemble galvanism, in the production of decomposition, and of the other effects, requiring “quantity” [53], by making its amount large, compared with the surface on which it is. This is accomplished by exposing only an exceedingly small point of fine platinum wire, in the fluid which is to be decomposed—the rest of the wire being protected by glass melted around it; and rendering the quantity of fluid extremely minute.

108. We are not to suppose that an expensive and complicated galvanic apparatus is required, even for important experiments.—Wollaston ignited a wire of platinum the $\frac{1}{3000}$ th of an inch thick, with a zinc plate one inch square, placed between two plates of copper; and he obtained highly interesting and important results, by means of very small and simple batteries.

109. A mode of expressing the phenomena of galvanic decomposition, now very much used, was suggested by Faraday; it is the more valuable since it does not involve any theory.—The extremities of the polar wires [27] are termed *electrodes*:* the positive or that from which the positive electricity is supposed to pass, being called the *anode*;† and the other the *kathode*.‡ Decomposition is termed *electrolysis*.§ The substance decomposed is an *electrolyte*; and its elements are *ions*||—each being an *anion*, or *kation*, according to the pole to which it goes.

Since the zinc is supposed to give electricity, through the fluid, to the other metal, it has been called the *positive* element of the battery, and the *positive pole*: the other metal being considered as the *negative* element, and *negative pole*. But I have already [17] expressed my doubts, as to the accuracy of this opinion: and have never used these terms, in this manner.

110. PHYSIOLOGICAL, &c., EFFECTS OF GALVANISM.—When we are to act on good conductors—the metals, for instance—we use large plates, in order to produce a considerable effect; but

* *Odos*, a way. Gr. † *Ana*, upwards. Gr.

† *Kata*, downwards. Gr. § *Luo*, I set free. Gr.

|| *Iōn*, going. Gr.

when on imperfect conductors—such as the animal body—we employ a number of circles. To give even a trifling shock—except with the cast-iron battery [42]—twenty circles, at least, are required. In this case, the size of the plates is of little consequence:—a battery, capable of giving a very violent shock, has been enclosed in a walking-stick. Under favourable circumstances, an effect is perceived both on making and breaking contact.

111. The intensity of galvanic electricity being very low, to transmit it fully, not only is a good conductor required, but, in addition, one of sufficient grossness. More perfect contact, also, is necessary:—hence the shock obtained from a galvanic battery is greater, when the wires are held with wetted hands; and the effect is still further improved, if the wires from the poles terminate in metallic cylinders which are grasped firmly; or if they dip, respectively, into vessels containing a solution of common salt—in which the hands are to be immersed.

112. When the effect is produced by a single circle, even the most perfect contact will not suffice: and, to effect the transmission of the electricity, the extremities of the wires which are to be united, in order to complete the circuit, must be amalgamated with mercury, and then placed in a small quantity of that metal. The use of mercury is, however, attended with several inconveniences; and it may, generally, be dispensed with, if small binding screws, something like what is represented fig. 283, are employed to make the connexions.—One of the wires to be united, is screwed in at D: and AT, the other wire, passing through B, is fixed tightly by the screw H: communication may thus be made, and broken, with great facility. Sometimes the connexions are conveniently effected, by platinum terminations, attached to the wires, &c.: and, as the platinum is not oxidized by the atmosphere, it affords, for many purposes, a sufficiently good connexion by mere contact.

FIG. 283.



113. Galvanic electricity, has, sometimes, been found beneficial in medicine, particularly in the pains which remain after rheumatic affections have been removed. And Dr. Wilson Philip [Phil. Trans., 1817] has shown that asthma—with the exception of the spasmodic kind, which depends rather on the contraction of the glottis, than on the nerves, and is rare—may be temporarily relieved, and often permanently cured, by the application of wires, connected with a galvanic battery. One of these wires terminating in a small metallic plate, is to be laid on the nape of the neck; and the other terminating in a similar plate, on the pit of the stomach—the number of gal-

vanic circles being gradually increased, until the effect becomes troublesome to the patient.

114. The galvanic and nervous fluids are, if not identical, extremely similar.—Indeed some have attempted to show that the brain is a species of galvanic battery: and galvanic circles have been produced, which consisted of animal substances. Thus, Lagrave formed a galvanic battery with alternate layers of human muscle and brain—pieces of moist cloth, or leather, being interposed. Galvanism is capable of affecting, though not always, nor to a considerable extent, the heart and stomach—over which the will has no control.

115. If the eighth pair of nerves, on the action of which the process of digestion depends, are divided, difficulty of breathing, tendency to vomit, and incapability of performing the function of digestion, are the consequence:—all these, however, are prevented, by transmitting the galvanic fluid, through the lower portion of the divided nerves.

116. On the whole, we have reason to believe, from experiments made, at various times, on malefactors who have been hanged, that life might, in certain cases, be restored by galvanism—which is capable of again putting into action the organs of respiration. And I have myself, more than once during my experiments on this subject, by means of it, caused animals, apparently lifeless, to revive.—It is needless, however, to remark that, in such cases, death, if it may be called by that name, must have arisen from the animal machine having been, as it were, merely *stopped*: and not from organic injury, or the destruction of any of its important parts.

The *magnetic effects* of galvanism will be considered, when I treat of “electro-magnetism.”

117. OTHER SOURCES OF ELECTRICITY.—While examining the properties, &c., of galvanic electricity, I may very conveniently treat of that which is derived from other sources, more or less connected with the subject.

118. *Thermo-electricity** is so called, because it arises from change of temperature. Seebeck of Berlin discovered, in 1802, that electricity may be developed, by causing the temperature of solid bodies to become unequal. The electricity is perceived only during *change* of temperature, and is different when the body is becoming heated, from what it is when the body is being cooled.

119. If the substance, operated on, is in the form of a ring, no electrical disturbance will be perceived, unless there is an obstacle to the transmission of the heat—such, for instance, as a knot on the wire of which the ring is formed. This produces a current *from* the point at which the heat is applied,

* *Thermē*, heat. *Gr.*

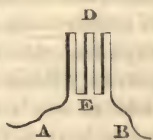
towards the retarding cause. Two metals, differing in conducting power, will afford the required obstacle; and if their point of contact, is at a different temperature from that of the other portions, a current will be produced, from that point, towards the metal which is the worse conductor. The greater the difference of conducting power the more marked the result. Those metals which, like bismuth and antimony, produce crystals belonging to different systems, are the best for the purpose.

120. The simplest form of thermo-electric battery consists of a piece of iron wire, connected with one extremity of the helix of a delicate galvanometer—an instrument which will be described hereafter—and a piece of copper wire, connected with the other extremity. On uniting the unconnected extremities of the wires, between the thumb and finger, the needle of the galvanometer will be deflected.—Electricity has, therefore, been produced by the very slight alteration of temperature.

121. A more powerful combination may be formed, by soldering together plates of bismuth and antimony, and arranging them as represented fig. 284—the former being indicated by the light, and the latter by the dark lines: wires A, and B, constitute the poles of the battery. To

FIG. 284.

develope the electricity, a bar of red hot iron must be placed at D: and the apparatus should, if possible, be put in contact with ice, at E.—The alternate joinings are thus, very conveniently, rendered hot and cold, respectively: and so much electricity is obtained, as will be quite sufficient for the performance of many of the experiments, usually made with a galvanic battery. The limbs of a frog have been convulsed by thermo-electricity.



122. The low intensity of this kind of electricity, prevents the construction of a large thermo-electric battery: for its current is greatly impeded, by the increased length of the conductor—although it is metallic.

In all metals, except zinc, iron, and antimony, the current is from the hot, towards the cold part.

123. *The thermo-electric multiplier of Nobili*, is a thermo-electric battery. It consists of fifty small bars of bismuth and antimony, placed parallel to each other, in a bundle AB, fig. 285,

FIG. 285.

about an inch and a quarter long, and three quarters of an inch thick: and having both its ends blackened. The two kinds of metallic bars are placed alternately, and are soldered together



at their extremities—like those already described [121]; and

they are separated, throughout their length, by some insulating substance. Copper wires, terminating in copper pins P, P, are connected, respectively, with the first and last bars :—these pins, which are intended to be connected with the galvanometer, are inserted in a piece of ivory, attached to a metallic ring, between which and the bundle is interposed a non-conductor. To prevent lateral radiation, the metallic tubes, F, F—bright outside but blackened within—are placed on the metallic ring D. The pile is so fixed on a stand, that its axis may be turned in any direction. It is excited by raising, or lowering, the temperature of the surface at one end, compared with that of the surface at the other.—Such an instrument is capable of indicating a change of temperature, equivalent to the $\frac{1}{3000}$ th part of a degree of Fahrenheit.

124. If changes of temperature produce electricity ; currents of electricity, on the other hand, produce changes of temperature. This is proved, by transmitting electricity through a thermo-electric battery ;—the joinings, which would be hot if the electric current were produced by heat, will become hot during its transmission. If the current is passed in the opposite direction, the same joints will become so cold that the mercury of a thermometer, the bulb of which is inserted in an aperture made in one of its junctions, will be frozen.

125. *Electricity produced by pressure, &c.*—If a piece of Iceland spar, after being carefully dried, is pressed between the finger and thumb, it will cause the leaves of the electrometer [elect. 8] to diverge.

126. The violent separation of the particles of bodies, also, developes electricity.—If a piece of dry wood is torn asunder, the two portions will be found oppositely electrified ; and, at the moment of separation, a spark will, sometimes, be perceived. It is thought that this fact enables us to explain the light seen, occasionally, when icebergs come into collision.

127. *Electricity produced by change of form.*—If melted sulphur is poured into a conical glass, and a hook of wire is inserted in it, for the purpose of lifting it out of the glass when cool, it will, on being applied to the electrometer, cause the leaves to diverge ; and this effect may be produced, each time it is taken out of the glass, for several months. Some attribute the electrical excitement to the friction, caused by drawing it out.

128. *Hydro-electricity.**—Electricity is developed by the evaporation of water. This may be proved, by pouring some water—it answers better, if not distilled—into a metallic dish, which has been placed on the cap of a gold-leaf electrometer. On dropping a live coal into the fluid, the gold leaves will

* *Hudör*, water. Gr.

diverge ; and both the water, and the vapour rising from it, will be found oppositely electrified.

129. Violent shocks have been received, by persons forming a communication between a boiler and the escaping steam, when substances, capable of conducting electricity, were placed in the latter.—On this principle, a most powerful electrical machine has been constructed, by insulating a boiler similar to that of a locomotive engine ; and causing the steam to gush out against a number of metallic points, which communicate with the earth. The extremity of the nozzle, attached to the pipe through which the steam issues, is made of a bad conductor—to prevent the re-union of the electricities : and the steam is received on the metallic points—for the purpose of dissipating the positive electricity, as fast as it is produced, and thus preventing the neutralization, which would arise from a positively electrified atmosphere, acting on the boiler. A disc is placed in the path of the escaping steam, as much as possible to increase the friction—which, according to Faraday, produces the electricity.

130. *Electrical Fishes*.—It has long been known, that certain animals possess, as a means of defence, or of aggression, the power of giving electric shocks. Their electricity—like every other [elect. 20]—is conducted, or not, according to the nature of the substances through which an attempt is made to transmit it. The animal is greatly affected, by giving a number of shocks, in rapid succession.

CHAPTER IX.

MAGNETISM.

History, &c., of Magnetism, 1.—Nature of Magnetism, 7.—The Dip and Variation of the Needle, 11.—Compasses, 18.—Action of the Magnet, on Iron and Steel, 22.—Action of the Iron in Ships, on the Needle, 27.

1. HISTORY, &c., OF MAGNETISM.—Magnetism* is a peculiar property, possessed by iron, and, to a less extent, by some other metals, which causes them—according to circumstances—to attract, or repel each other. It was very anciently remarked in the *loadstone*—a species of iron ore, which attracts ferruginous substances or those containing iron. But, although the properties of the loadstone were familiar to mankind, from the earliest ages, the history of magnetism, as a science, commenced but a few centuries ago.

2. The great utility of the magnet depends on its *directive power*; that is, on its tendency to arrange itself in a certain position—with reference to the poles of the earth. This property enables us to construct an instrument, the most simple, but at the same time, the most important, that the ingenuity of man has ever devised; one, without which, the mariner would cross, with fear, the narrowest seas; but, under the guidance of which, the boundless ocean is traversed, with the greatest facility. The magnet was used in ships by Flavio Gioia, about the year 1302:—however, its first application to the purposes of navigation, is a subject which has given rise to much dispute. The knowledge of its properties is said, by some, to have been brought from China in the thirteenth century; and we are told that it was used by the Chinese, many hundred years before Christ.—It would appear, that they first applied it to the guidance of chariots, in front of which they placed a small figure of a man, which, by means of a magnet, was made constantly to turn to the south, their sacred point.

3. Iron is not the only metal attracted by the magnet.—Nickel, also, is magnetic:—but it ceases to be so, at 630° . Manganese, according to Berthier, is magnetic at a very low temperature. Iron loses the power of being attracted by the

* *Magnētēs*, a loadstone, *Gr.*—so called from Magnesia, a city of Asia Minor, where it was first discovered.

magnet, at an orange red heat ; steel is deprived of its polarity by the temperature of boiling almond oil ; and a loadstone just below visible ignition.

4. The loadstone itself, which consists of the peroxide of iron, with some silex and alumina, is but little used :—steel is more manageable, and may be made, by friction with the magnet, to possess all the properties of the loadstone in a superior degree. Common or soft iron, is highly susceptible of magnetism :—a metal containing only the $\frac{1}{130000}$ th part of its weight of iron, a quantity that can scarcely be discovered by any other means, will often give magnetic indications. Iron is magnetic, only while it is near a magnet—which may be proved by bringing a small iron key, &c., in contact with it ; the moment the magnet is removed, the key falls.

5. Magnets are of two kinds, the *bar*, and the *horse shoe*. The former is represented by D and E, fig. 286 : and the latter by H. A bar of soft iron A, B, or S, which is termed the *keeper*, cannot be separated from the magnet, without a force depending on the power of the latter. And, if a scale P is attached, while the keeper is in contact with the magnet, weights may be added gradually, until the magnet attains its maximum power—which, sometimes, does not occur for a considerable time.

6. The keeper must be kept on the magnet, when the latter is not in use : otherwise it will deteriorate. A bar magnet should be left in that position which, if capable of moving, it would naturally assume : or, what is better, two similar bar magnets D and E, fig. 285, should be arranged parallel to each other, their opposite poles being turned in the same direction, and being in contact with the same keeper—which should be of very soft iron.

A slender magnetized bar of steel, capable of turning freely on a pivot, is termed a *needle*.

7. NATURE OF MAGNETISM.—The magnetic, like the electric fluid, is of two different species ; and seems to reside at what are called the “magnetic poles,” which are near the extremities of a magnetized bar.—It is curious that the earth appears to have more than two magnetic poles : those which are “secondary,” it is probable, are produced by large masses of iron.

8. Similar poles repel, but those which are opposite, attract

FIG. 286.



each other.—Before an electrified body attracts another, in its natural state, it induces electricity of the opposite kind, on that side of the body which is next to it [elect. 44]. In the same way, a magnet, before it attracts iron, &c., which is not magnetic, induces the opposite species of magnetism, on the side which is next to it.—A magnet will attract a greater weight, with one of its poles, if a piece of soft iron is in contact with the other.

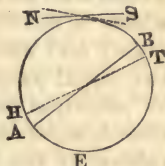
9. Magnetic attraction is exerted in curves:—this may be shown by scattering iron filings on a sheet of paper, which is held over a magnet. These curves are of a peculiar order, each pole being the centre of its own series.

10. Magnetic attraction and repulsion, like the electric [elect. 10], is inversely as the square of the distance:—but it has been found that, when the distance is less than the one-fourth of an inch, or, when the magnets are very large, so much even as half an inch, the attraction or repulsion is inversely as the distance. When the two magnets differ greatly in power, the change may, as far as repulsion is concerned, take place, while they are still farther asunder.

11. THE DIP AND VARIATION OF THE NEEDLE.—If a bar of steel, which has been accurately balanced on a point—so as to remain at rest in a horizontal position, is magnetized, its equilibrium will be destroyed; and it will make an angle with the horizon, which is called the *angle of dip*. The reason of this will be obvious, if we consider the earth E, fig.

FIG. 287.

287, as a great magnet, of which the magnetic poles are A and B. Let NS be a magnetized bar, resting on a point, at any place of the earth nearer to one pole B, than to A the other. It is evident that B, from its greater proximity, must exert a more effective action on S, than the pole A, on N. Consequently S must be drawn nearer to the earth than N: and the magnetized bar will assume a position, resembling that indicated by the dotted line. The earth is capable of magnetizing rods of iron, left sufficiently long in a proper position: hence, fire-irons, and the bars of windows, are generally found to be magnetic.—We shall see hereafter how its magnetism is produced.



12. When it is necessary that *the needle* should be horizontal—which is almost always the case—one of its extremities must be rendered heavier than the other, to prevent the dip: and the nearer the needle is to a magnetic pole of the earth, the greater must the additional weight be.

13. The angle of dip is continually changing; in 1723 it was $74^{\circ} 42'$ at London; but it has, since that time, diminished, though not regularly. At the magnetic equator there is no dip:

at the magnetic poles, the needle would have a tendency to become perpendicular to the horizon.

14. Let E, fig. 287, represent the earth, and AB its magnetic axis. A needle at any point of the surface of the earth will, if capable of doing so, move round in a horizontal direction, until it rests with its axis in the same direction as AB. And, if the magnetic and terrestrial axes were coincident, the needle would point due north and south. This, however, is not the case; for the magnetic axis AB makes an angle with the earth's axis HT, which is called the *angle of variation*, and is the same as that made by the plane of the magnetic with the plane of the terrestrial meridian, belonging to the place where the needle is.

15. Like the angle of dip [13], the angle of variation is constantly changing; but more rapidly. And, besides the *secular* changes of variation, there is an alteration in the position of the needle, at different parts of the day; and at different seasons of the year. The variation of the compass is, at present, 24° west of north; having gradually altered from being several degrees to the east—to which it is at present returning. The annual change was about $10'$; but it is now less.

16. The indications of the needle are affected by light.

17. The intensity of magnetic attraction, at a given place, is determined by the number of oscillations, made by the needle, before it assumes a state of rest.

18. COMPASSES are, in general, shallow circular boxes of metal, &c., containing in the centre of their interior, a point on which a needle turns freely:—over the needle is a plate of glass; and under it a card, divided, in most cases, into thirty-two equal parts, by lines, called *rhumbs* or *points*. The north, or principal point, is ornamented with a *fleur de lis*—introduced, according to some, by the French; and, according to others, by the Neapolitans. The angle formed by the meridian and the rhumb on which the ship sails, is called “the ship's course.”

19. The details of the compass are different, according to the purposes for which it is intended. Sometimes the *card* revolves—the needle being fixed to its under surface, and along its north and south line. This is the case with the *mariner's* compass; which, also, is so suspended that, however irregular the motion of the ship, it maintains the same position with regard to the horizon.

If the compass is intended to be very perfect, a contrivance is added, for lifting the needle off the point, when it is not in use.

20. The size, form, &c., of the needle, are of considerable importance. It should be only so thick as will prevent its bending with its own weight. For, it is found that, if a magnet

is placed beside another—the similar poles being in contact—its power is diminished, by the reactions of those polarities, which are of the same denomination: and a thick needle may be supposed to consist of two or more thin ones, placed together. Hence, doubling the thickness will not double the directive force, as, while it doubles the weight and the friction at the pivot, it diminishes the sensibility. There is no advantage gained, by lengthening a needle—but the contrary: for, if the directive force is increased, the weight and friction are augmented, to the same extent; and, besides, a long needle is liable to have several consecutive poles—which interfere with each other. The form that has been found most proper for a needle, is a *rhombus*—two triangular pieces being cut out of the middle, so as to leave a bar, in the direction of the shorter diagonal. A small hollow cone of brass is fixed in the centre of this bar; and at the vertex of the cone—which is turned upwards—is a small piece of agate, to prevent injury from wear. The pivot on which the needle turns is of hard steel; and, since it passes up into the cone, the centre of gravity of the needle is under the point of suspension—which [mech. 97] causes the equilibrium to be stable. Shear steel answers far better for a magnet than cast steel.

21. *The azimuth compass* has, on its circumference, two *sights* which are perpendicular to its plane, and are used for marking the position of an object. The angle made by the needle, with a line passing through the sights and a given object, is the “horizontal angle,” or the “angle of azimuth:” and it is ascertained by the graduation of the instrument. A compass of this species is sometimes used in surveying; and when—for the purpose of greater accuracy—the sights are placed at some distance from the circumference of the compass-box, it is called a *circumferentor*. The compass used for surveying, &c., has generally but eight points.

22. ACTION OF THE MAGNET, ON IRON AND STEEL.—The magnet acts both on iron and steel; with this difference, however, that its effect on the former is transitory [4]: while, on the latter, it is more, or less permanent—remaining, indeed, until it is deranged, or destroyed, by some other magnetic agency. The harder the steel, the more lasting the magnetism it can be made to receive; but it is the more difficult to be magnetized.

23. The inductive influence, exercised by magnets on bars of steel, gives rise to various methods of forming artificial magnets; none of them, however, is so important to our purpose, nor so greatly superior to the rest, as to require a detailed description.—It will be enough to remark, that, whatever may be the shape of the intended magnet [5], we must cause the bar

with which we magnetize it, to act in such a way as, that one of its poles shall neither counteract, nor disturb the effect of the other. Hence, each pole of the bar to be magnetized must be rubbed constantly in the same direction, with the proper pole of the magnet, the other being kept as far away as possible.

24. A blow, or any thing else which throws the particles of the steel into a vibratory motion, facilitates the communication of magnetism. Heat is productive of the same effect:—a bar of steel will be powerfully magnetized, if, when heated, it is cooled suddenly near a magnet, or in other circumstances, favourable to magnetization. Whatever facilitates the acquisition, will facilitate, also, the loss of magnetism.

25. A magnetized ring of steel will not show any magnetism, unless broken—when each piece will be a magnet. This reminds us of electricity, not indicated by an electrometer, when in presence of the opposite kind [elect. 43: and gal. 19]; and also of what occurs with a thermo-electrical ring [gal. 119], &c.

26. A magnet is neutral, in the centre; but, when cut, each part is a magnet.

27. ACTION OF THE IRON IN SHIPS, ON THE NEEDLE.—Besides the causes of disturbance which give rise to “dip” and “variation,” there is another productive, sometimes, of serious inconvenience, and consequent on the nature of the material, stores, &c., in the ship. This is a source of great danger: and, no doubt, has often led to fatal accidents.—It has, for some time formed the subject of an interesting, most important, and, still, only partially successful inquiry, to ascertain how the effect, produced by the iron work, guns, &c., of a ship, may be counteracted. The means which have been employed are, an equal and opposite action, obtained from a smaller mass of metal, rendered more efficient by its nearness to the needle.—But, unfortunately, were the adjustment ever so perfect, it cannot be permanent; since, particularly in ships of war, the iron must constantly change its place, and quantity. The derangement of the needle from this cause is one of the difficulties attending the use of iron ships which, more especially in steam navigation, have very considerable advantages.

28. Our knowledge of magnetism has been greatly increased by the discoveries and experiments, to be detailed in the next chapter.

CHAPTER X.

ELECTRO-MAGNETISM.

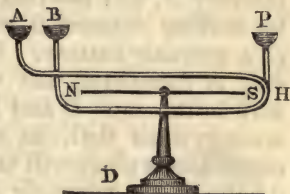
History of Electro-magnetism, 1.—Action of the Conductor, on the Magnet, 2.—Magnetic Rotations, 6.—The Galvanometer, 8.—Electro-magnetic Induction, 12.—Electro-magnetism as a Moving Power, 16.—The Electric Telegraph, 20.—Secondary Currents, 24.—Magnetism, produced by Rotation, 35.—Identity of Electro-magnetism, and Terrestrial Magnetism, 41.

1. HISTORY OF ELECTRO-MAGNETISM.—The connexion between electricity and magnetism was long known; but Oersted, in a paper published in Thompson's Annals of Philosophy for 1820, left the nature of this connexion no longer a matter of uncertainty. The manner in which the various facts, &c., of electro-magnetism, were successively ascertained and developed, is not so important, considering our subject, as to claim a particular notice.

2. ACTION OF THE CONDUCTOR, ON THE MAGNET.—Oersted pointed out the remarkable fact, that, not only those metals which were hitherto considered to be magnetic, but any conductor, might be made to exhibit the properties of the magnet; and that, for such a purpose, it is necessary merely to make it form a communication between the poles of a galvanic battery. This important principle was established, by the conductor, in such circumstances, attracting iron filings—by its arranging itself, when at liberty, in a certain position—by its magnetizing other bodies, inductively—and by its action on the needle.

3. The effect produced upon the needle NS, fig. 288, by the conducting wire AH, or BH, when electricity is transmitted through it, is the great fact upon which the whole science depends; and, it not only leaves no doubt that the body, along which the electricity is transmitted, becomes a magnet, but it enables us, also, to discover that the polarity of the conducting body is at *right angles* to the direction of the electric current—that it depends on the direction of the current, whether a given side of the conductor shall have a northern, or a southern polarity—and that the mutual action of the conductor and the needle, is modified by the different positions, in which one is placed, with reference to the other. When connexion is made with the battery, by means of the mercury cups [galv. 112] A and P, the conductor

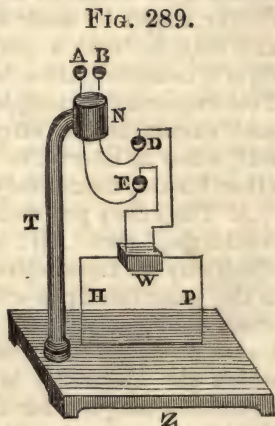
FIG. 288.



will be *above* the needle: but when, by B and P, *below* it: and, the north pole of the needle being in the one case deflected in a certain direction, it will in the other, be deflected in exactly the opposite. Also, the point, towards which a given pole will be deflected, is different, according as the electric current runs in a certain direction—for example, from A to H, fig. 288, or in the opposite—from H to A. It follows, from these facts, that if both the direction of the current and the side of the needle are changed, the effect will suffer no alteration. Hence, if a current is sent through the whole conductor AHB, the action of the part between A and H, will be the same as that of the part between H and B. The deflection of the needle will, by consequence, in this case be doubled.—A recollection of this fact will be useful, when I speak of the *galvanometer*.

4. Ampere has given a very simple rule, which enables us to say what, under any given circumstances, shall be the position, that the needle will assume.—We have only to suppose ourselves parallel to the conductor, and that the direction in which the electricity passes, while going from the positive to the negative pole [gal. 10, and 21] of the battery, is from our head to our feet:—and, if the needle is in front of us, its north pole will move to the right, but if at our back, in the contrary direction, &c.

5. The *directive power* of the conductor—or its tendency to arrange itself north and south—may be exhibited, by the following apparatus. The extremities of a wire HP, fig. 289, which is curved as represented, and passes through a piece of wood W, dip into cups of mercury D and E: the latter are connected, respectively, by wires which pass through another piece of wood N, with cups of mercury A, and B—that are intended for making connexion with the poles of a galvanic battery. When the circuit is completed, the wire HP will turn in the cups D and E, and will so arrange itself that—as might be anticipated—its plane will become perpendicular to the magnetic meridian. The earth, in this case, has acted like a magnet [mag. 11], upon the conducting wire.



6. **MAGNETIC ROTATIONS.**—The mutual action of the magnet and conductor, gives rise to a number of what are called “magnetic rotations.” The most important of these are, the revolution of the magnet about the conductor, and the revolution of the conductor about the magnet. Also the revolution of the magnet on its axis:—in which case, the magnet itself becomes

the conductor ; since the electricity is transmitted along it ; and may be supposed, either to pass *down its sides*—when it will be an example of a conductor revolving about a magnet ; or *down its centre*—when it will be an example of a magnet revolving about a conductor.

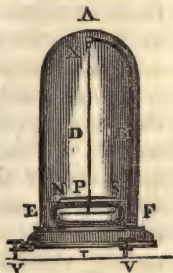
7. These, and many other magnetic rotations, are explained on the principle of the resolution of forces [mech. 132].—There is a tendency in the conductor and magnet, to fix themselves mutually at right angles ; and the force which causes this tendency is constantly resolved into others—one of which being tangential, gives rise to a rotary motion. In such experiments, only one pole must be affected, or there will be equal and opposite actions, and, consequently [mech. 107], no motion.

8. THE GALVANOMETER.—The mutual action of the conductor and needle, enables us to construct an instrument for the purpose of ascertaining the presence, and measuring the amount of extremely minute quantities of electricity. The effect of the galvanic current is increased, by causing it to pass both above and below the needle [3] : and still further, by its being carried round the needle several times—in which case the various parts of the same current produce nearly the same effect as so many different currents, acting together. If a silver is used, instead of a copper wire, it may, on account of being a much better conductor, be made considerably thinner :—a greater number of coils will then extend to only the same distance from the needle—which, as will be seen presently, is important.

9. A small current of electricity may not be able to overcome the tendency of the needle to arrange itself in a particular position ; but this inconvenience is removed, by rendering the needle *astatic*—that is, by neutralizing its directive power. This is effected, by adding another similar needle : and combining both, in such a way that their opposite poles are next each other.—It is better, however, that the directive power should not be totally destroyed.

10. Fig. 290 represents a galvanometer, constructed on these principles. Two needles, one within and the other above the coil of wire, are delicately united together, and suspended by D—the single thread of a silkworm, &c.—from X the upper extremity of a bent brass rod, fixed in the stand T. Under the upper needle, is a graduated annular card EF, the edge of which is just perceptible in the figure :—it rests on the coil. This indicates the number of degrees, through which the needle moves, when deflected. The instrument is adjusted, by means of the three screws VVV, on which it stands :

FIG. 290.



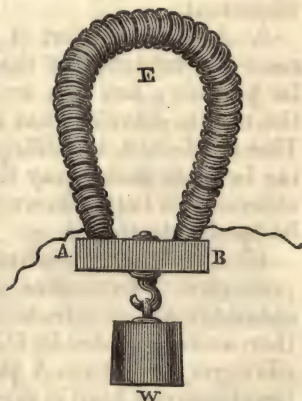
and a glass shade protects the needles from being disturbed by currents of air, and from being easily injured.

Sometimes four needles are used ; but the increased inertia [mech. 5] more than counterbalances any advantage.

11. However strong a galvanic current may be, the deflection produced by it, cannot, with the ordinary galvanometer, exceed 90° . Hence, for the purpose of measuring large currents, and of comparing two or more, a *torsion galvanometer* has been constructed so as very much to resemble the torsion electrometer [elect. 12]. The lower part of it contains the coil and compound needle—which is suspended by a fibre of glass, and may be moved, at the top, to any extent which the strength of the current, under examination, may require.

12. ELECTRO-MAGNETIC INDUCTION.—If the conducting wire is coiled round a bar of soft iron, while a current of electricity is passing through the former the latter will be magnetized : and the effect will be greatly increased, if the coil of wire is made to pass round the bar, so as to form several layers. Such a coil is termed a *helix* [mech. 279]. It is impossible for the spirals to be exactly at right angles to the bar : but the injurious effect, arising from their unavoidably improper position in the first layer of wire, will be counteracted by the equally injurious but opposite effect of their position, in the second. A piece of iron, thus coiled, is called an electro-magnet ; and it may, like the ordinary magnet, be in the form either of a bar, or of a horse shoe [mag. 5]. Fig. 291 represents one of the latter kind—which, generally speaking, is the more convenient. E is the iron coiled with wire, the extremities of which are seen near the ends of the keeper AB, to which is attached the weight W.

FIG. 291.



13. There is a limit to the size of an electro-magnet, because there is a limit to the number of coils : since when these are too far from the bar, their action—which decreases inversely as the square of the distance—will be inconsiderable [8] ; and will not compensate for the diminution of the conducting power of the wire, caused by its increased length. This diminution is very serious, on account of the low intensity of the electricity [gal. 13] : but it is partially prevented, by causing the different layers of wire—or even different parts of the same layer—to form separate lengths, and uniting their corresponding extremities with two thick pieces

of wire, which are to be connected, respectively, with the poles of the galvanic battery. The several lengths of wire, act then, as one thick piece, and will more perfectly conduct the electricity.

14. A bar of steel, placed within a helix, will be permanently, but not powerfully magnetized. If a magnetized bar, or needle, is placed in a helix the axis of which lies horizontally, when the extremities of the helix are connected, respectively, with the poles of a galvanic battery, the bar, &c., will immediately be suspended in the middle of it. The most effective kind of electro-magnet is constructed of soft iron. If it is not perfectly soft, as far as magnetism is concerned it approximates to the nature of steel [mag. 22]. Iron is rendered as soft as possible, by being heated to redness, and then gradually cooled. Electro-magnets have been made sufficiently powerful to keep suspended, a weight of at least 2,000 lbs. The keeper must bear some proportion to the size of the magnet, or it will not produce a maximum effect.

15. The wire of the helix must be covered with a non-conducting substance, such as cotton, worsted, or silk; otherwise the electricity will pass directly across from one part of the coil to another, and not along the wire.

16. ELECTRO-MAGNETISM, AS A MOVING POWER.—The very great force exerted by electro-magnets, soon suggested the idea of adopting electro-magnetism as a moving power. For this purpose, systems of enormous magnets have been constructed; and appropriate apparatus has been applied to destroy, or reverse the polarity of all the magnets at once, or of portions of them in succession—so that bars of soft iron should be alternately attracted, and repelled by all, or be attracted by one portion, and repelled by another. But I conclude, from experiments made by myself, on a very large scale indeed, that there are obstacles in the way of obtaining power from electro-magnetism which, if not insuperable, are by no means likely to be overcome. It would be attended with but little profit, to describe any apparatus used for the purpose, either by myself or others. Among the difficulties, experienced in such experiments, it is found that electro-magnets—particularly when of a large size, and separated by small spaces—interfere seriously with each other: that the repulsion of the electro-magnet, consequent on the sudden reversion of its poles, does not always cause the bar which has been attracted to be thrown off: that the action of electro-magnets, however powerful, is exerted within only extremely short distances: that the galvanic battery, necessary for any thing like a considerable effect—with all that has been done to improve galvanic apparatus—is both troublesome and expensive; and finally, that the simplest form of

electro-magnetic apparatus which has yet been devised, is far more complicated, and difficult to manage, than a steam-engine of the same power.

17. *Electric clocks*.—After it was ascertained, that motion could be produced by means of electro-magnetism, the application of it to the movement of clocks, very naturally suggested itself. The attainment of such an object, was greatly facilitated by the discovery of methods for the construction of constant batteries [gal. 34, &c.] : and it has been attempted even to call in the aid of terrestrial magnetism, for this purpose.

18. It is evident that the bob of the pendulum, fig. 83, may very easily be made to consist of a bar of soft iron, which will be alternately attracted and repelled, by electro-magnets placed at a convenient distance on each side of it. In this case, the pendulum would move the wheel E, which, ordinarily, is kept in motion by it : there is no difficulty, however, on this point, since either effect is produced, with nearly equal facility. The details of such a contrivance, it is evident, may be greatly varied.

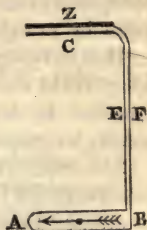
19. The best application of electro-magnetism to clocks, appears to be the regulation of a great number of them, so as to make their indications perfectly agree : an object which, in many cases, is extremely desirable. For this purpose, one good ordinary clock will be sufficient—its pendulum being arranged in such a way as alternately to make and break connexion with a battery ; so that, electricity, sent at the proper times through a wire, will, by means of an electro-magnetic arrangement, put in motion the required number of clocks. All of them must then, evidently agree with that, by the movements of which—through the medium of electricity—they are all really kept in motion.

20. **THE ELECTRIC TELEGRAPH**.—Among the wonderful results, arising from the development of the principle discovered by Oersted [2], none is more curious nor important than its application to the purposes of the telegraph. In the ordinary telegraph,* certain signals, agreed upon, are made visible from station to station ; and thus intelligence is conveyed along the entire line. Among the inconveniences, however, to which such an arrangement is evidently subject, not the least is the difficulty, in certain states of the weather, of rendering signals visible, even at moderate distances. But, with the electric telegraph, a message can be transmitted, either by night or day, with the greatest ease, certainty, and expedition.—By means of it, indeed, space itself seems almost annihilated ; for it enables us to converse with a person, hundreds of miles distant, as easily, and almost as rapidly, as if he were in the same room with us.

* *Télé*, at a distance ; and *grapho*, I write. *Gr*.

21. It is not necessary to describe the details of the various plans, which have been proposed for carrying out this object. The principle on which all of them are founded, will be easily understood from fig. 292.—Let us suppose that there is a coil and needle AB, in Cork : and a galvanic battery ZC, in Dublin. If there is a proper communication established, between AB and ZC, by means of wires E and F, the battery in Dublin will cause the needle in Cork to be deflected, with as much certainty—and almost as much rapidity—as if the intervening distance were but a few inches : and thus, a mode of correspondence between the two cities will be established. If the current is reversed, the needle is deflected in the opposite direction ; which, at once, affords another signal with the same needle. But its capabilities are by no means confined to these.—Two deflections in one direction, two in the opposite direction : three in one direction, three in the other, &c., may evidently be all used, for communicating different intelligence.

FIG. 292.



22. To such a pitch of perfection are the details already brought, that not only can the most complicated information be conveyed to, and from the most distant places, and those which are intermediate ; but, also, by means of self-acting machinery, it may be noted down and even printed. A letter at one end of the line can be copied at the other. For this purpose it is written with metallic ink, and placed in the apparatus, in such a manner, that metallic points pass over it. These points are moved by weights brought into action through the agency of an electro-magnet—which lifts a latch when under the influence of the electric current : and, while in contact with the metallic ink, they complete the voltaic circuit. The electricity is transmitted by corresponding points at the other end of the line, through paper wetted with a chemical substance which is blackened by it : and the writing made with metallic ink is copied on the prepared paper—which retains its whiteness in the other portions, through which no electricity is transmitted by the points. Thus the facsimile of a letter at one end of the line is produced at the other. Type may be employed, instead of the paper and metallic ink, the points not being allowed to sink into the spaces : and a book hundreds of miles off, may be printed by it.

23. The wires of the telegraph are insulated, by being passed through porcelain rings, fixed in the supports which, at certain distances, sustain them, at a considerable height above the ground. This insulation is still further secured, by a waterproof covering, that at the same time preserves them from the action of the atmosphere : and in some countries, they are

carried under ground. It is proposed to convey the wires across narrow seas; so that it is quite possible a time may yet arrive, when persons in London, Paris, or Dublin may communicate with those in Petersburg or Pekin: and with nearly as much ease, as we now converse in the same apartment. The telegraphic communication between London and Paris will very soon be completed.

It is curious that the wires of the electric telegraph are affected by certain electrical states of the atmosphere, and in some instances, to an inconvenient degree; means, however, are now taken to convey the atmospheric electricity to the ground.

24. SECONDARY CURRENTS.—Oersted made the important discovery [2] that currents of electricity produce magnetism: it subsequently occurred to Faraday, that magnetism, on the other hand, ought to produce electric currents—that, in fact, magnetism and electricity are always co-existent; and experiment showed the correctness of his opinion.

25. If a bar of soft iron is coiled with insulated wire [15]—as it always must be, for the purpose of electro-magnetic experiments, so often as the bar is magnetized by bringing its poles across or very near those of a permanent magnet [mag. 22], a current of electricity is generated in the helical wire: and it may be made perceptible, by means of the spark it produces, if, at the same instant, both the soft iron is demagnetized and the continuity of the helix is broken by lifting one of its terminations or poles out of a mercury cup, &c., which connects it with the other. The electric current, thus produced, is denominated “secondary,” and is capable of decomposing water, of magnetizing iron, of giving a shock, &c., like ordinary galvanism—with which, therefore, it may be considered identical. Increasing the length of the wire in this, and all similar experiments, increases—within certain limits—the *intensity*: increasing its thickness, increases the *quantity* of the electricity produced.

26. The secondary current is perceived, both when the bar is magnetized, and when it is demagnetized.

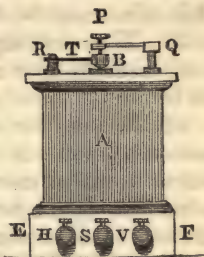
27. We may generate a secondary current with an electro-magnet, by coiling two helices, at the same time, round a bar of soft iron, and passing an electrical current through one of them:—electricity will then be perceived, in the other.

28. A bar of iron, within the helix, is not absolutely necessary: but it increases the effect—which becomes still greater, if a bundle of soft iron wire is used instead of the bar.

29. During a long series of experiments, which I made some years ago, on electro-magnetism, a very convenient and powerful machine for giving shocks suggested itself to me, from a consideration of these facts—for most of which, we are indebted to Faraday. The experiment was pursued by Dr.

Callan of Maynooth, and others, with great success; and the result has been an instrument, which, for medical purposes, has almost superseded the electrical machine. It may consist of a mahogany box A, fig 293, in which is placed a tube of thin wood—or, what is better, of pasteboard—having a flange on each end, so as to form a kind of bobbin. In the original instrument, I made this bobbin of brass, that it might be able to bear the pressure of the strong wire I then used. A helix of tolerably thick insulated copper wire is coiled on this bobbin, from one end to the other:—the ends of the wire project through the wooden box, and terminate in binding screws [gal. 112], so as to be easily connected with the battery: over this helix, is coiled a quantity of extremely thin insulated copper wire, sufficient to fill the bobbin. Short pieces of wire are soldered in different places on this fine wire, and each of them, as well as each extremity of the entire coil, is connected with one of the binding screws placed round E F, the base of H. A secondary current of electricity [27] may thus be obtained, at pleasure, either from the entire helix, or from only a portion of it. Within the vertical tube of the bobbin is placed a bundle of very soft iron wire, on the upper end of which rests a piece of extremely soft iron, projecting through the upper surface of A. On the top of the latter, are fixed two brass studs R and Q, forming part of the circuit—which is complete, if a small cylinder of soft iron B, fixed on the spring T, is in contact with the screw P. When this is the case, the bundle of wire becoming magnetized, the piece of iron which rests upon it, attracts B, and drawing it down from P, breaks battery connexion. This causes the bundle of wire to lose its magnetism:—on which, the iron attached to B is, by the elasticity of the spring raised up so as to come again in contact with P, and form a perfect circuit. This magnetization and demagnetization goes on with such rapidity, that a humming noise is produced [pneum. 69] by the striking of B against the end of P. And one curious consequence of the shocks succeeding each other, with such extreme rapidity is, that if metallic cylinders, connected with two of the binding screws which are fixed round the base of A, are grasped in the hands, it is impossible—when the secondary helix is of considerable length—to let them go: so that the person receiving the shock, is detained at the pleasure of the operator.

FIG. 293.



A small piece of platinum [gal. 112] is soldered on the extremity of P—which is adjustable in the end of the brass bar P Q; and another, on B, where it comes in contact with P.

30. The primary helix—or that in connexion with the battery—is short and thick, that the electricity may be transmitted [gal. 13] with facility. The great length of the secondary helix, causes the electricity, excited upon it, to have an enormous intensity;—and is no inconvenience, since it is to be excited, not by transmission, but by induction. It is useless, however, to increase the length of the secondary coil, beyond a certain extent:—perhaps the resulting increase of intensity causes some of the electricity to be dissipated, and thus renders the effect less than it ought otherwise to be. About 300 feet of thin wire may be considered as sufficient.

31. The primary helix, alone, without a secondary, will if long enough, give a shock, each time battery connexion is made, or broken.

32. When the circuit, belonging to either a primary, or a secondary helix is interrupted, by raising an amalgamated wire out of a cup of mercury [gal. 112], some of the metal is burned, a brilliant spark being produced each time contact is made, or broken—but particularly in the latter case.

33. The principle of the apparatus just described [29] has been used by Delarue, to increase the power of an electrotype battery [gal. 65]. In the intervals, during which the helix is in connexion with the generating cell, less electricity passes through the decomposing cell, on account of the opposition caused by the length of the wire [gal. 13]; but this inconvenience is more than counterbalanced, by the quantity transmitted from the helix, when the connexion is broken.

34. *Action of the electric current, on light.*—We have seen [2] that magnetic induction is not confined to those bodies which, for a long time, were deemed alone capable of becoming magnetic: but it has been shown, also, by Faraday, that substances, in the vicinity of an electric current, have their molecular arrangement so altered, that even the plane of polarization [opt. 210] may be affected by it.—If a ray of polarized light is transmitted through glass, which is between the poles of a magnet, or which has an electric current passing round it, the glass acquires the power of causing the plane of polarization of the ray, to revolve through an angle that is proportional to the intensity of the current. Hence, not only do the molecules of a conductor tend to assume a peculiar arrangement, but this tendency is exhibited even by non-conducting bodies in the vicinity of the current.

35. **MAGNETISM, PRODUCED BY ROTATION.**—If a disc of copper, or of any other substance, is made to rotate under a magnetized bar, capable of moving round in a plane parallel to the disc, the magnet will revolve in the same direction: and the amount of effect produced, will depend on the nature of the substance of which the disc is formed.

36. This result does not arise from a current of air ; since it occurs even when a plate of glass is interposed : but is due to magnetic induction acting on that diameter of the disc which happens to be under the bar. This is evident from our being able to produce an electric current, by means of such a rotation.—

37. Dr. Faraday caused a copper plate, twelve inches in diameter, to revolve between the poles of a powerful horse-shoe magnet—its centre and circumference being each attached to a wire. When these wires were brought into connexion, the needle was deflected 90° , and sometimes 45° permanently, by the current passing through them. When the motion was reversed, a deflection in the contrary direction was produced. A similar result was obtained, when the magnet was made to rotate on its axis. An electro-magnet would cause the same effect.

38. A marked difference was perceived, according as the substance used in the disc, was or was not susceptible of ordinary magnetization.—If an iron disc was made to revolve between opposite poles, they neutralized each other's effects, and no electricity was produced : but the effect was increased, when the iron was between similar poles—and a single pole was sufficient. If copper was substituted for the iron, similar poles neutralized each other : but opposite poles increased the effect : and a single pole produced none. When the magnet revolves on its axis, electricity of the same kind is collected at its poles ; and of an opposite kind, at its equator.

39. Since fluids are affected by magnetism, and have electric currents developed in them, the gulph stream may have some influence on magnetic variation.

40. The disc [37] forms an electric apparatus, differing from the plate machine [elect. 66], in being a conductor, and having the effect destroyed by insulation ; and by affording electricity of low intensity. Probably, as Dr. Faraday remarks, the earth, like the magnet, produces by its rotation, currents negative at the equator, and positive at the poles.

41. IDENTITY OF ELECTRO-MAGNETISM, AND TERRESTRIAL MAGNETISM.—The fact that electric currents produce magnetism [2], enables us, very easily, to understand how the earth must necessarily be magnetic [mag. 11]. For, we have seen that change of temperature is a source of electricity [gal. 118]:—hence, since the various portions of the earth's surface, during revolution on its axis, become successively heated and cooled, as they successively approach to and recede from the sun, vast quantities of electricity must be derived from this cause. Also, evaporation is a source of electricity [gal. 128]:—hence, the evaporation which takes place over the surface of the earth, must produce enormous electrical effects.

42. The action of the earth, as a magnet [mag. 11], may be still further illustrated, by connecting the extremities of a helix with a galvanometer, placing it in the magnetic dip, and then suddenly inverting it several times—accommodating its motion to the oscillations of the needle. The latter will soon vibrate through a very large arc.

The effect is increased, by placing a bar of soft iron in the helix:—and it may be produced, by simply removing the bar.

43. The magnetization of the earth by electric currents, can be strikingly illustrated, by a sphere of wood, covered with wire coiled parallel to its equator.—If, when electricity is transmitted through the wire, a needle is placed on points fixed in different portions of its surface, the dip and variation [mag. 11 and 14] may easily be made intelligible to any one.

44. The phenomena exhibited by revolving plates [37], may be produced by terrestrial magnetism. For this purpose, a copper plate is to be connected with the galvanometer, by two copper wires—one at its centre, and the other at its circumference. When the plate is made to revolve in a plane passing through the line of dip, the galvanometer is not affected; but when in a plane inclined to it, electricity is developed—and, to a greater extent, in proportion as the angle is greater, being greatest at 90° .

CHAPTER XI.

HEAT.

Importance of Heat, 1.—Theories, concerning the Nature of Heat, 5.—Sources whence Heat is derived, 6.—Conduction of Heat, 11.—Radiation of Heat, 21.—Absorption, and transmission of Heat, 25.—Reflection of Heat, 34.—Expansion caused by Heat, 38.—Thermometers, 51.—Pyrometers, 68.—Specific Heat, 75.—Latent Heat, 77.—Evaporation, 83.—The Dew Point, 94.—The Hygrometer, 95.—Ebullition, 106.—Freezing mixtures, 114.

1. IMPORTANCE OF HEAT.—The word heat, is used sometimes to indicate a peculiar sensation; and, at others, to express the cause of that sensation. I shall apply it in the latter meaning only; but, as much as possible, to avoid ambiguity, I shall generally use, instead of it, the word *caloric** which has been very generally adopted, in science, and is never employed to express the sensation.

2. We shall have some idea of the importance of heat, if we recollect that, without it, neither animal nor vegetable life could exist. Were it annihilated or removed, the earth would be a solid mass; gases would be changed to fluids; and they—as well as all other fluids—would become solids. On the other hand, if the heat were to become sufficiently intense, the hardest solids would ultimately assume the gaseous form:—indeed, the comparatively limited amount of heat, we can command, is sufficient to change all solids but charcoal into fluids, and all fluids into vapour.

3. Heat modifies the conducting power of bodies:—for red hot glass is a conductor [elect. 20]. It renders them capable, or incapable, of magnetic excitement:—cold manganese is, but red hot iron is not magnetic [mag. 3]. Heat imparts malleability:—for zinc is not malleable, unless heated to the temperature of boiling water. It very often modifies colour; thus binocide of mercury, when sublimed, is yellow—until cooled below a certain temperature, at which it becomes red. Peroxide of mercury is nearly black, when hot; but red, when cold. Protoxide of lead is red, while hot; but lemon-coloured, when cold. Protoxide of zinc is white at ordinary temperatures: but yellow, at a low red heat. These changes of colour are due to a different molecular arrangement, produced by heat. It sometimes, however, arises from other causes:—thus, rubbing the

* *Calor*, heat. *Lat.*

binoxide of mercury, will effect the alteration of colour produced by a change of temperature.

4. Heat has a great effect on crystallization, not only when the particles are free, but even when the substance is in the solid form. Mitcherlich found that primitive crystals of sulphate of nickel, exposed in a close vessel to the heat of the summer's sun, had their internal structure so altered—without being changed externally—that, when broken, they were composed of octohedrons with square bases. And prismatic crystals of zinc are, in a few seconds, changed by the heat of the sun into octohedrons.

5. THEORIES CONCERNING THE NATURE OF HEAT.—Light and heat are, probably, of the same nature. There are two similar opinions regarding each [opt. 3].—According to some, heat is merely the *vibration* of a material substance. This opinion seems to have originated with Lord Bacon: and to have been held by Newton, and Boyle. Others maintain, that it is a subtile fluid; and it has even been attempted to establish this fact, by proving that it increases the weight of bodies.—But we cannot rely on such experiments: since there are so many circumstances which would prevent their accuracy: and the increase of weight, if any, must be too trifling to be appreciated, by the most sensitive apparatus that can be constructed. There are, indeed, certain facts in chemistry, which seem to indicate that heat enters into chemical combination with the elements constituting bodies: and that it is disengaged, like other substances, when these bodies are decomposed. If however, heat and light shall be ultimately found identical, which is very likely to be the case, the question of the nature of the one will resolve itself into that which concerns the nature of the other. It is not necessary for us to adopt either opinion.

6. SOURCES WHENCE HEAT IS DERIVED.—The sources of heat are various. Some geologists suppose, that the internal portion of the earth is itself a great magazine of heat—having been once in a state of fusion; and that, even yet, only a comparatively thin crust, has cooled down to the solid form. There is, indeed, every reason to believe that the temperature increases, at the rate of about one degree, for every fifty feet of descent from the surface of the earth. At the depth, therefore, of 200 miles, the hardest substances must be in a state of fusion; and, consequently, the earth must be a globe of liquid fire 7,600 miles in diameter, covered with a comparatively thin crust.

7. This opinion is strengthened by the fact, that the temperature of mines increases as we descend; and that the lava, thrown out from volcanoes, is capable of retaining its heat—even near the surface—for years. Were the elements of matter allowed, after creation, to act on each other, according to the laws which

chemistry teaches us at present regulate their combination, the heat generated during the formation of their various compounds, would suffice to account for the very elevated temperature within the globe; and, also, for the high temperature which, there is some reason to believe, formerly existed in regions which now are extremely cold. The universal law, which causes tides in the sea [mech. 17] and atmosphere [mech. 26] produces also, most probably, tides though small ones, in the molten mass within the earth.

8. There are many other sources of heat—the sun—compression, to which may be reduced friction, and percussion—chemical action, which will include the heat derived from animals and vegetables, &c.

9. The friction of wood generates caloric, better than that of metal:—however, the heat, developed in boring cannon, is sufficient to raise a large quantity of water to the boiling point. Hence, to prevent the instruments from being softened, oil, or water is often used in drilling, turning, &c., metals.

10. The friction of fluids does not generate heat.

11. CONDUCTION OF HEAT.—Every one has remarked, that some bodies conduct heat, better than others. Hence, we can hold a rod of glass, but not a rod of metal, within an inch of the part of it which is red hot. If a piece of paper is wrapped closely round a tolerably thick metallic rod, it may be kept for some time in the flame of a spirit lamp, without its taking fire:—the metal conducts away the caloric, and thus prevents it from accumulating. If a rod of wood is used, the paper will be burned. The non-conducting power of certain substances, is applied to a variety of purposes:—thus the handles of metallic teapots are made of wood, ivory, &c.: or they are separated from the teapot, by pieces of ivory—which is a bad conductor.

12. Geology furnishes us with a curious example of this property, in the fact of a large quantity of ice being preserved, unmelted, under a mass of lava that had flowed over, and become consolidated upon it.—This was probably due to the nonconducting power of some substance with which it was covered.

13. The dress we wear, does not impart any heat: but it prevents that which is produced by the body, from escaping. Wrapping ourselves with clothes, in winter, keeps us warm, because the heat we produce is retained; in summer the same clothes would keep us cool, by excluding the heat. For a similar reason, a thatched cottage is warmer in winter, and cooler in summer than one that is slated—thatch being a worse conductor than slate. Snow—a bad conductor—prevents the earth from being cooled to a very low temperature: and is an important means for preserving the roots of plants.

14. The metals are excellent conductors of heat—gold being

the best. The power of conducting heat bears a relation to the capability which bodies possess of transmitting electricity : but it is more intimately connected with their densities.

15. The relative conducting power of different metals, &c., is as follows—

Gold,	1,000	Tin,	304
Silver,	973	Lead,	180
Copper,	898		
Platina,	381	Marble,	23·6
Iron,	374	Porcelain,	12·2
Zinc,	363	Fire clay,	11·4

16. According to the experiments of Count Rumford, the following substances required, to cool a thermometer, imbedded in them, through the same number of degrees—

	Seconds.		Seconds.
Air,	27	Raw silk,	1,283
Fine lint,	1,032	Beaver's fur,	1,296
Cotton wool,	1,046	Eiderdown,	1,305
Sheep's wool,	1,118	Hare's fur,	1,315

17. Fluids cannot be heated by placing the fire above them, since they conduct caloric very imperfectly. When it is applied beneath them, the stratum of fluid next the bottom having its temperature raised, and by consequence expanding, ascends [hyd. 39]; its place being supplied, by a different and colder portion. The same cause produces wind [pneum. 104]. Currents, generated in a fluid, while it is being heated, become very perceptible, if it contain small particles of solid matter suspended in it.

18. This ascent of the hotter, and descent of the colder portion of fluids, is sometimes employed as a means of warming houses, and also of supplying their different parts with hot, or cold water.—For this purpose, one vessel placed at the bottom, and another at the top of the building, are connected by pipes, which, by the tortuous direction given to them, are made to traverse the apartments to be heated, several times. When fire is applied to the lower vessel, a rapid circulation commences: the hot water ascending in one pipe, which projects into the fluid at the higher part of the upper vessel: and the cold descending in another, which passes down into the fluid in the lower vessel. Since [hyd. 8] the pressure on the pipes is considerable, they should be made tolerably strong. Care, also, must be taken, to prevent danger from any steam, that may happen to be generated. If cocks are attached, in the different corridors, &c., to the pipes through which the hot and the cold water is, respectively, passing, hot or cold water may be, at any time, obtained, without the trouble of carrying it from one place to another.—Steam, also, has been used for heating buildings.

19. This property of fluids, being wanting in those which are thick—such as water-gruel, &c.—they become hot, or cold very slowly, as one stratum cannot easily rise, or fall, so as to give place to another. When a thin skin is formed upon them, the process of cooling is rendered still slower, the heat being confined by the badly conducting solid covering.

20. Heat is communicated from one body to another, either by *contact*, or by *radiation*. Communication by contact, depends on the conducting power, both of the substance which imparts, and of that which receives the heat; and on the amount of surface, in contact. Some circumstances worthy of notice, arise from heat being communicated to bodies, which are not good conductors.—Thus a glass tube may be broken in any particular part, by heating that part, and then suddenly plunging it into mercury. The effect is produced, by the sudden abstraction of heat, which causes the unequal contraction, and consequent fracture of the glass. A crack, made in a piece of glass, will follow heated iron applied a little beyond its extremity, and drawn gradually over the surface, in the path of the intended fracture:—an unequal expansion is caused, by the heat being concentrated, in considerable quantity, on a small space. This method of cutting glass, is very convenient in the laboratory: since it enables us to use, even what has been broken. A large soldering iron—which retains the heat, for a considerable time—answers well for the purpose; and its point enables us to follow, with great accuracy, a line, &c., marked out with chalk, &c.

21. RADIATION OF HEAT.—Caloric escapes from a heated body, as from a centre, in all directions, and in right lines:—it is, therefore, said to “radiate.”* These rays are either *absorbed*, *transmitted*, or *reflected* by the surrounding bodies.

22. The best absorbers are, also, the best radiators. Dark and rough substances, generally speaking, radiate heat the most perfectly. Hence, if any thing is to be kept, either hot, or cold, it must be smooth, and of a light colour: thus, the surface of a teapot should be polished—because it is to be kept hot: a dark and rough one ought not to answer well, for the purpose. Fire-irons must be kept bright, but for a contrary reason—because they are to remain cool. The darkness of the colour affects absorption, more than radiation.

23. Leslie found the relative radiating power of the following substances to be—

Lampblack,	100	Plumbago,	75
Writing paper,	98	Tarnished lead,	45
Crown glass,	90	Clean lead,	19
Ice,	85	Polished iron,	15
Red lead,	80	Other bright metals,	12

* Radius, a ray. Lat.

24. A cast silver plate, not subjected to pressure, has, when quite bright, a radiation represented by 22: but when it is dimmed, by being rubbed with sand paper, its radiating power is diminished to 12. Highly elastic substances such as ivory, or very hard ones such as agate, radiate to the same degree, whether rough or smooth. All smooth bodies are not equally imperfect radiators:—glass radiates better than smooth metal. Air does not seem either to accelerate, or retard, the radiation of heat.

25. ABSORPTION AND TRANSMISSION OF HEAT.—When heat is transmitted through media, generally speaking, a greater or less amount of it is absorbed. Heat, which has passed through a given substance, will have very little more of it absorbed, in passing through another plate, of the same substance.

26. The more intense the source of the heat, the more easy its transmission, through a given medium.

27. Some substances, capable of transmitting light, do not transmit caloric:—thus, the thinnest glass intercepts the obscure rays, flowing from a body whose temperature is lower than that of boiling water. As the temperature increases, however, the calorific rays are transmitted more abundantly. The brighter the object whence the rays come, the more freely they pass through glass; the heat of a common fire, but not that of the sun, is intercepted by a screen of glass. Perfectly black glass transmits heat abundantly, but intercepts light. Rock-salt transmits light and heat, with equal facility. Thin and perfectly transparent plates of alum, and of citric acid, transmit all the light, but intercept most of the heat of an argand lamp. Brown rock crystal intercepts nearly all the light, but none of the heat.

28. If rays of heat from a lamp, are transmitted through a rock-salt prism, they will be differently refracted;—the most refrangible calorific rays will correspond with the middle of the luminous spectrum [opt. 105]; and the least refrangible, will extend far beyond the least refrangible rays of light.

29. Since [27] rock-salt will transmit any of the calorific rays, it is, to heat, what perfectly colourless glass is, to light. Glass, gypsum, &c., allow the mean and least refrangible rays of heat to pass—just as orange coloured glass, allows the mean and least refrangible rays of light. Alum transmits the least refrangible rays of heat, as red glass transmits the least refrangible rays of light. Rock-salt, coated with soot, intercepts the least refrangible rays of heat:—and, therefore, such a plate, along with a plate of alum, is as impervious to heat as a plate of red, combined with a plate of green glass [opt. 202] is impervious to light.

30. Melloni's experiments seem to indicate a distinction [5]

between light and heat.—He obtained calorific rays of all refrangibility, unmixed with luminous rays, by using quartz black mica and rock-salt coated with soot. But, by combining a plate of alum with glass coloured green, he obtained a brilliant light, so free from calorific rays that, even when concentrated by a lens, it did not affect the most delicate thermoscope.

31. There are other differences, also, between light and heat. One kind of light has never been changed into another—thus, red into blue. One kind of heat has :—thus, if the light of the sun is passed through alum, and received on a black surface, the latter will radiate caloric which will not pass through alum. Heat, radiated at a temperature of 212° , may be made, by concentration, to heat a small surface beyond 212° : and the refrangibility of the rays will be diminished.

32. Some remarkable phenomena are explained by these facts. Thus the sun's light passes freely through ice, and snow—but little of its heat being absorbed. If, however, a dark object is placed on the snow, its heat will be absorbed by it; and the calorific rays, then radiating from a lower temperature, become refrangible, and are absorbed by the ice or snow.

33. There appears to be a great difference, as to radiation and absorption, between the sun's rays, and those from artificial sources.—A body will be heated, by an ordinary fire, equally soon, whether it is painted black or white : which is not the case when it is exposed to the rays of the sun.

34. REFLECTION OF HEAT.—If two spherical mirrors, A and B, fig. 294, are placed opposite to each other, when a live coal or a lighted candle L is put in the principal focus of A, a thermometer in the principal focus of B will rise, on account of the heat reflected to it, from L. If, however, L is removed, and replaced by a lump of ice, a curious result is obtained : for the thermometer will fall—which would seem to indicate that, in this case, *cold* is reflected : and that, consequently, it is not a mere negation—the absence of heat. But the fact is easily understood, if it is remembered, that the thermometer was maintained at a certain temperature, not only by the candle, but also by radiation from the mirrors themselves, and from all the surrounding bodies. Some of the heat derived from this radiation, being intercepted by the ice, the thermometer must necessarily stand lower than if the ice were not present.

FIG. 294.



35. The relative reflecting power of the following substances is—

Polished gold,	76
„ silver,	62
„ brass,	62
Unpolished brass,	52
Polished brass, varnished,	41
Looking-glass,	20
Glass plate, blackened on the back,	12
Metal plate, blackened,	6

36. When heat is reflected, the angles of incidence and reflection are equal [mech. 136]. In this respect also, it resembles light.

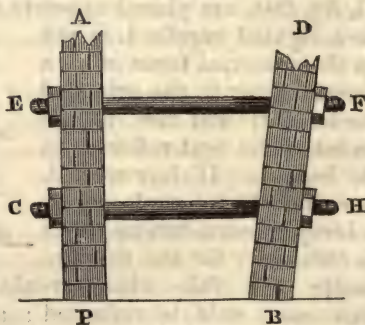
With the same body, when the quantity of heat is constant, reflection and absorption vary inversely:—for, when much is absorbed, less remains to be reflected; and *vice versa*.

37. Heat can be polarized, like light [opt. 118 and 210], and seems in this respect to follow similar laws.

38. EXPANSION, CAUSED BY HEAT.—All bodies, whether solid, fluid, or gaseous, are found to be expanded by heat. Thus a piece of iron, when heated, will be too large for the aperture, which it fitted exactly, when cold.

39. The expansion of metals, caused by heat, was used, with success, to restore the walls of the *Gallerie des Arts et des Metiers* at Paris, to their original perpendicularity.—Bars of iron EF and CH, fig. 295, were made to pass through the walls AP and DB: and nuts attached to their extremities were screwed up as tightly as possible. Alternate bars being then heated, their length was increased by expansion: and their nuts were screwed up still further. The bars, on cooling, contracted, and drew the walls together, with great force. This process was repeated, until the walls were brought to their former position.

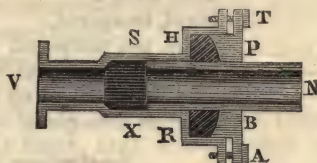
FIG. 295.



40. In laying down iron joists, setting steam boilers, &c., provision must be made for expansion: otherwise the brickwork or masonry, will be forced out of its place. When the metallic body is of considerable length, it is necessary to provide for the effects of, even ordinary changes of temperature.—Hence, in the suspension and tubular bridges which have been constructed at the Menai Straits, &c., the effects of expansion are carefully guarded against.

41. The expansion of pipes is often a source of much inconvenience. When those which lead from steam-boilers, or which are employed for the conveyance of water, are long, *expansion joints*, something like what is represented fig. 296, should if possible, be used.—A portion of the

FIG. 296.



pipe V is enlarged, so as to allow the pipe N to move longitudinally within it, when the length of either is increased by a rise of temperature. Leakage is prevented by a *stuffing-box*, which contains a ring of hemp capable of being pressed tightly between the pipe N and HR, by the metallic ring or *gland* PB—which is moved easily, but with great force, by means of the screws T and A. That extremity of N, which is within the stuffing-box, slides freely—though, at the same time, water, or steam tight—within the ring of packing. A more simple, but very efficient contrivance, of a similar kind, allows the gas, or water pipes, laid down in streets, &c., to contract, or expand.—The end of one pipe fits into a socket cast in the extremity of the next; a quantity of hemp is forced in between; and the joint is rendered still more permanent, by melted lead, which is poured outside the hemp. Cast-iron pipes are lengthened about six inches in 900 feet, by the change from winter to summer.

42. In making wheels, the iron rim is put on, when very hot; and, while cooling, it contracts so forcibly, as to draw the different parts strongly together. Cast iron contracts, in cooling, about one-eighth of an inch to the foot.—Hence the patterns must be larger than the intended castings. And, to save troublesome calculation, the pattern maker employs a *contraction rule*:—that is, one in which the feet, inches, &c., are about the one-ninety-sixth part longer than in the usual standard measure.

43. Sometimes the expansion, consequent on increased temperature, is very sudden, and—if the substance is a bad conductor—very unequal. Hence, hot water, poured into a glass vessel, will break it, on account of the external and internal surfaces being torn asunder, by the unequal expansion. If a metallic spoon is present, this effect is more likely to be produced, since the heat is then accumulated in one spot. Plate electrical machines [elect. 67] have been broken, by being placed opposite to a fire, on account of the two surfaces being unequally heated—the temperature of one of them being, probably, rendered still lower by a current of cold air, passing to the fire.

44. The following are the rates, at which a few of the most important substances are found to expand, with a change from the temperature of freezing to that of boiling water:—

Equal lengths of	Of their length.
Brass, according to Lavoisier and Laplace,	$3\frac{1}{5}7$
Silver,	$5\frac{1}{2}4$
Copper,	581
Pure gold,	602
Iron wire,	812
Steel, tempered,	807
Steel, not tempered,	927
Glass tube, without lead,	1115
Platinum, according to Borda,	1167
English flint glass,	1248

Equal volumes of	Of their volume.
Nitric acid, according to Dalton,	9
Alcohol,	9
Fixed oils,	12.5
Ether,	14
Oil of turpentine,	14
Hydrochloric acid,	17
Sulphuric acid,	17
Water, saturated with salt,	20
Water,	21.5
Mercury,	50

Since the expansion of alcohol is so considerable, its temperature, when bought or sold, becomes a matter of some consequence :—its volume will, evidently, be greater in summer than in winter.

45. The expansion of metals, &c., and their fusibility, appear to be connected.—Platinum, which expands the least, is also the least fusible; lead is both very fusible, and very expansible; the glass which is most fusible, is most expansible.

46. Cooling contracts bodies; but water under 40° is an exception to this law, since, below this temperature, it continues to expand, and with most rapidity at the moment of freezing. By this wise provision, ice, being specifically lighter than water, floats upon it:—if such were not the case, rivers and seas would be permanently frozen, except near the surface. Anchors, and other heavy bodies, are sometimes raised to the surface of the water, by a casing of what is called *ground ice* being formed around them. Decanters are often broken, by the water which they contain, being frozen; also, pipes used to convey water, &c. The force exerted by water, at the moment of freezing, is irresistible.

47. If it is kept perfectly at rest, water may be cooled below 32° , without solidifying:—but the slightest motion causes it immediately to freeze: and the temperature then rises to 32° . In the same way, certain saline solutions do not crystallize, if kept perfectly quiet, even though they are quite saturated; but

a gram of sand, or a crystal dropped into them, or the slightest motion, causes crystallization, accompanied with the evolution of heat, to be produced, at once.—The temperature, in such cases, always rises to that at which, under ordinary circumstances, the solid would be formed. These effects arise from the fact, that motion is required to overcome the inertia which prevents the assumption of a different form.

48. Salt, or vegetable acids, lower the temperature at which water freezes: and the ice formed when these solutions are frozen, is almost pure. Hence the ice mountains of the polar seas, contain water which is nearly fresh, and is very often of great use to navigators in frozen seas. Captain Cook found the water produced from it extremely well tasted. Water containing sulphuric acid, &c., is rendered chemically pure by congelation, not the smallest trace of them being discoverable in the resulting ice.

49. Frost loosens earth, and crumbles rocks:—geologists attribute the disintegration of the latter, principally, to this cause, which, also, frequently overturns old walls, banks of earth, &c., in the winter. It breaks up the clay, and thus renders it more fit for the purposes of the agriculturist.

50. It is probable, that the expansion of water, while being frozen, is due to some arrangement of the particles during crystallization, which may cause them to occupy a larger space. Some fluids do, and some do not expand, before they assume the solid form. Cast iron belongs to the former class; and may, therefore, be cast in moulds, since the impression will be sharp: for, all the angles and edges will be thrown into the fullest relief. Gold, silver, &c., belong to the latter class:—hence, in the production of coins, medals, &c., they must be stamped with dies.

Metals that distinctly crystallize in cooling, such as cast iron, &c., give good sharp castings; gold, and the others, which do not crystallize, give very bad ones.

51. THERMOMETERS.*—The invention of these instruments has been attributed to various philosophers: among others, to the celebrated Galileo—to Santorio, a Venetian physician, afterwards professor at Padua—to Cornelius Drebbel, a Dutchman, &c. They were improved by Boyle, and others. The expansion caused by heat, is used as a means of measuring the *relative* amount of *sensible* caloric or that which comes under the cognizance of the senses;—this expansion, within certain limits, is found to be regular. Air, and the other gases, expand more than liquids; and liquids more than solids. Hence, air is well adapted for the purpose of constructing a very delicate thermometer:—but its range cannot be extensive, since the

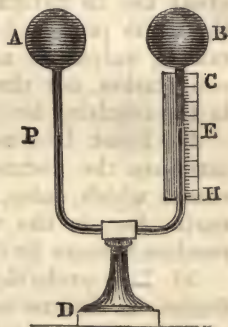
* *Thermē*, heat; and *metreo*, I measure. Gr.

expansion caused by a few additional degrees of heat, will make it occupy a much larger space. Alcohol will allow a greater range, mercury one still greater, and the solid metals one that is very great—the delicacy of the instrument continuing to decrease, as the extent to which it is capable of indicating change of temperature is enlarged.

52. Most air thermometers have the disadvantage of being affected by the pressure of the air, which [pneum. 32] is changeable. Leslie's differential thermometer, however, is free from this defect. It consists of two glass bulbs, A and B, fig.

FIG. 297.

297, connected by a glass tube, and filled with air—except the dark part from P to E, which contains sulphuric acid, coloured with carmine. This fluid is selected because it does not give off vapour. When the air in one bulb A is expanded by increase of temperature, that in the other, is condensed. A scale CH, marks the difference between the spaces occupied by the air, in the two portions of the instrument. Since the bulbs and tube are hermetically sealed, they are equally affected by everything, except the disturbing cause—the body whose temperature is to be tested, and which is brought near to only one of them.



53. The ordinary thermometer consists of a bulb B, fig. 298, having a fine stem D, formed of a capillary tube [hyd. 97]. The bulb, and the stem as far as T, are filled with mercury: from T to D there is a vacuum.

FIG. 298.

54. To construct this instrument, a piece of tube of the proper length, and having a bore as even as possible, is carefully selected. That end at which the bulb is to be formed is first hermetically sealed, and then thickened by continuing to throw upon it the flame of the blow-pipe. In blowing the bulb, it will be proper to use air forced from a bladder, or silk bag; as moisture from the mouth, once introduced into the tube cannot [hyd. 104] be expelled:

The bulb is slightly heated to rarify the air within and, the open end of the stem being plunged into mercury, is allowed to cool:—this forming a partial vacuum the mercury is forced into it by atmospheric pressure [pneum. 32]. The small quantity of mercury, now within the bulb, is boiled until the whole interior contains only mercury, or its vapour; after which, the stem is again plunged into mercury:—the vapour



is condensed by the cold, and the whole interior is completely filled with the fluid.

55. The thermometer is next to be exposed to something more than the highest temperature which it is intended to measure:—the mercury becoming expanded by heat, will flow out of the stem. If, on exposing it to the lowest temperature necessary, the mercury in the stem is distant more than a short space from the bulb, the stem is unnecessarily long; and a part of it may be broken off. When it is of a proper length, it is to be again raised to as high a temperature as before; and the extremity of the stem is to be rapidly and carefully sealed with the blow-pipe, as near the mercury as possible.

56. To graduate the thermometer, it is to be immersed in boiling water, when the barometric pressure is thirty inches. Or, another thermometer, already graduated, is to be immersed along with it: and the temperature, at which the water boils—according to the graduated thermometer—is to be marked, opposite to where the mercury stands in the stem of the new one. The latter is next to be immersed in melting ice or snow: and 32° is to be marked, opposite to where the mercury then stands. The distance between the two marks is afterwards to be divided into the required number of degrees—which, if the water was boiled with a barometric pressure of thirty inches, will be 180° . These divisions may be continued below the freezing, and above the boiling points.

57. It has been found that the zero of a thermometer becomes displaced, after some time:—the change proceeds more rapidly, at first, and continues for from four to six months. It is supposed to arise from the glass requiring that period fully to contract—after being raised to an elevated temperature. The zero is brought back to its original place, by raising the temperature as high as before.

58. The delicacy of the thermometer depends on the size of the bulb, compared with the bore of the stem: for the larger the bulb, the greater the increased bulk of the mercury, with a given increase of temperature: and the greater, therefore, the additional distance, through which it will extend in the tube—but [51] the range will be proportionably small. In good thermometers, the section of the bore in the stem, is such as that the mercury within it is extremely thin, in one way, but tolerably broad, in another:—this causes it to be distinctly visible, even when very small in quantity. Though mercury is a very good conductor, it is found advantageous to make the bulb oblong and smaller at the lower extremity, &c., that it may the more rapidly be affected by changes of temperature. In making a thermometer, only mercury which has been purified by distillation should be used.

59. The principal thermometers, employed by philosophers, &c., are—

	Boiling point.	Freezing point.
That of Fahrenheit,	212°	32°
That of Reaumur,	80°	0°
The centigrade,	100°	0
That of De L'Isle, of St. Petersburg,	0°	150

Fahrenheit's thermometer is used in Great Britain; Reaumur's in Germany; the centigrade in France, and very generally by continental experimentalists; that of De L'Isle very rarely, except in Russia. The *zero* or 0° of Fahrenheit marks the degree of cold, which is obtained by mixing snow and salt—the lowest known in his time.

60. It is easy, and sometimes very necessary, to reduce the indications of one kind of thermometer, to corresponding ones in another.—For this purpose we can say, “as the distance between the boiling and freezing points in the one, is to the distance between the same points in another: so is the given number of degrees in the former, to the corresponding number of degrees in the latter.” When Fahrenheit's is one of the thermometers to be compared, 32° must be added or subtracted from the result—since the indications of that thermometer commence at 32° below the freezing point. When De L'Isle's is one of them, in looking for the result, it must be borne in mind that the graduation of that thermometer, is from the boiling to the freezing point. In Fahrenheit's, &c., temperatures lower than zero, are counted downwards from that point, and are negative. Thus, a temperature of −20° Fahrenheit, is 52° below the freezing point.

61. The following will illustrate the comparison of thermometers:—

EXAMPLE 1.—Find what degree of Fahrenheit corresponds to 70° of Reaumur. $80:180::70:\frac{180 \times 70}{80} = 157.5^\circ$, and $157.5^\circ + 32^\circ = 189.5^\circ$, the indication of Fahrenheit's thermometer, corresponding to 70°, Reaumur.

EXAMPLE 2.—Find the degree of centigrade, corresponding to 52°, Fahrenheit. $180:100::20 (52-32):\frac{100 \times 20}{180} = 11.1^\circ$, the required number of degrees, centigrade.

EXAMPLE 3.—What degree of De L'Isle corresponds with 78° Fahrenheit? $180:150::46 (78-32):\frac{150 \times 46}{180} = 38.33^\circ$, then $150 - 38.33 = 111.67^\circ$, the required number of degrees, De L'Isle.

EXAMPLE 4.—What degree, Fahrenheit, corresponds with -45° , centigrade? $100:180::45:\frac{180 \times 45}{100} = -81$. And $-81 + 32 = -49^{\circ}$, which corresponds with -45° , centigrade.

62. The comparisons may be effected with still greater facility, by using certain fractions, as multipliers.—Since a degree centigrade $= \frac{180}{100} = \frac{9}{5}$ of a degree, Fahrenheit, to reduce the latter to the former, we have only “to subtract 32° from the given number of degrees, to multiply the result by 9, and divide the product by 5.” And, to reduce centigrade to Fahrenheit, we are “to multiply by 9, to divide the product by 5, and add 32° to the quotient.”

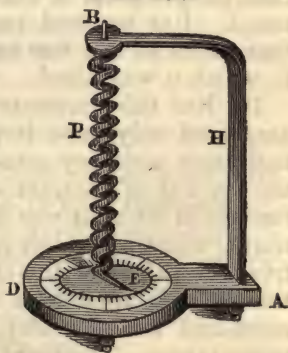
63. Since a degree, Reaumur, $= \frac{180}{80} = \frac{9}{4}$ of a degree Fahrenheit, to reduce the former to the latter, we are “to multiply by 9, to divide the product by 4, and add 32° to the quotient.”

64. And, to reduce Fahrenheit to Reaumur, we are “to subtract 32° , to multiply by 4, and divide the product by 9.”

65. Mercury is well adapted for a thermometer, since it does not freeze until -39° , nor boil until 662° . It seems to expand uniformly; because the increased expansion of the glass in the thermometer just balances the increased expansion of the mercury—except near the boiling, and freezing points, at which its contraction and expansion are very irregular.

66. The different extent, to which different metals expand with the same increase of temperature [44], has been applied, in the construction of what is called the thermometer of *Breguet*. It consists of a compound wire—formed of silver and platinum, united together with gold—flattened, and formed into a helix P, fig. 299. This helix is attached by its upper extremity to an arm BHA, fixed in the stand AD, on the upper surface of which is a graduated circle. At the other extremity is an index which moves round in a direction, depending on whether the unequal expansion of the silver and platinum causes the helix to be coiled, or uncoiled; and which indicates the corresponding temperature, on the graduated circle.

FIG. 299.



67. The self-registering Thermometer consists of two glass bulbs, A and D, fig. 300, connected by a glass tube. The bulb D and the stem, as far as P, are filled with alcohol: that part of the stem, between P and H, with mercury; and the re-

mainder of the stem, as well as a portion of the bulb A, with alcohol. A small piece of gilt iron wire, attached to a minute spring of glass, &c., floats on each horizontal surface of mercury, with just so much friction against the sides of the tube that, when raised up by that fluid, it does not fall down, if the surface on which it rests descends. The *highest* temperature, during a given time, is indicated on the scale QE, by the ascent of the iron index, which floats on the end of the mercury next H, and is raised—by the expansion both of the mercury and of the alcohol—in the space from D to H. Should the temperature fall, the index, at H, is prevented by the spring attached to it, from descending along with the surface of the mercury. The *lowest* temperature during a given time, is indicated on the scale SF, by the ascent of the iron index next P, which is elevated by the contraction of the alcohol: and which, being once raised, retains its position, on account of the spring attached to it.



The iron indices, previous to a new experiment, are drawn down to the surfaces of the mercury, by a magnet.

68. **PYROMETERS*** are intended to measure high temperatures. They are constructed in a variety of ways. Sometimes the pyrometer consists of a metallic bar, which is lengthened by the increase of temperature, to be measured; and the effect is magnified by levers, &c., so as to be appreciable. But it is difficult to prevent the necessary complication of such an instrument, from interfering with its accuracy.

69. *Wedgwood's Pyrometer* consisted of a piece of fine porcelain clay, formed in a mould, so that, when baked at a moderate temperature, it exactly fitted a notch cut in a piece of metal. But exposed to a high heat, it contracted: and the diminution of size was considered to indicate the temperature, to which it was raised.

70. But this pyrometer is not now used.—Since it could be employed only once, it could not be tested by comparing its indication with any standard: and, besides, it was found, that the amount of contraction depended both on the heat of the furnace in which it was first baked, and on the length of time, during which it was left in it. This is what should be expected, from the nature of the change, produced upon it.—Its diminution of bulk arose from more or less of the water, which was combined with the clay, having been driven off by the high temperature. The higher, therefore, the heat of the furnace in which it was prepared, the more of this water was separated by it, and the less during the subsequent experiment.

71. The contraction of baked clay, it is evident, forms no

* *Pur*, fire; and *metreo*, I measure. *Gr.*

exception to the law, according to which bodies expand by increased temperature; for the diminution of its bulk arises from diminution of the quantity of matter present; and the expansion due to the heat is not perceived, because it is more than counteracted by the loss of one of the ingredients which originally formed the mass.

72. In India the thermometer rises to more than 120° . The highest measured temperature, has been estimated at 32277° Fahrenheit; and the lowest at 180° below zero. Chinese porcelain softens at 21357° . The heat of a common fire is 790° . Iron welds at 13427° : and the highest heat of a smith's forge is 17327° .—But we cannot depend on the measurement of such elevated temperatures.

73. When the volumes of gases are taken, it is necessary, not only to make the correction for pressure [hyd. 61, and pneum. 42], but also that for temperature, by reducing the given volume to what it would be at a standard temperature—for example 32° .

74. It is inferred from the experiments of Regnault and others, that every rise in temperature equal to one degree, increases the volume of a gas, by about the $\frac{1}{492}$ nd part of its bulk at 32° . Hence, its volume at, for example, 58° , will be to that at 32° , as $492 + 26$ is to 492 ; since there are 26° , between the given temperature, and 32° . And the volume, at any temperature [hyd. 60], may be found, from the volume at any other, if we “multiply the given volume, by the sum of 492 and the difference between the temperature of the required volume and 32° : and divide the product, by the sum of 492 and the difference between the temperature of the given volume, and 32° .” *

EXAMPLE.—The volume of a gas, at a temperature of 54° is 37 cubic inches; what will be its volume, at 62° ?

The difference between the temperature of the given volume and 32° , is $54 - 32 = 22^{\circ}$. And the difference between the temperature of the required volume and 32° , is $62 - 32 = 30^{\circ}$. Therefore the required volume is

$$\frac{37 \times 492 + 30}{492 + 22} = 37\frac{1}{2} \text{ cubic inches nearly.}$$

75. SPECIFIC HEAT.—The specific heat of different substances, is the relative amounts required to raise them, respectively, through the same number of degrees of temperature. It might, at first, be supposed that a given quantity of caloric would raise any fluid, through the same number: which is not,

* Let x be the volume, corresponding to a difference t ; and x' one corresponding to a difference t' ;—the bulk at 32° being unity.

$$x = 1 + \frac{t}{492} = \frac{492+t}{492}; \text{ and } x' = 1 + \frac{t'}{492} = \frac{492+t'}{492}$$

$$\text{Therefore, } x:x'::\frac{492+t}{492}:\frac{492+t'}{492}::492+t:492+t'.$$

$$\text{Hence, } x = \frac{x' \times 492 + t}{492 + t'}; \text{ and } x' = \frac{x \times 492 + t}{492 + t'}.$$

however, the case. The fluid which is raised by the given quantity of caloric, through the smaller number of degrees, is said to have the higher *specific heat*. If we mix a pound of mercury, at 160° , and another at 40° , the mixture will stand at 100° , the mean. But if we mix a pound of mercury at 160° , and a pound of water at 40° , the temperature of the mixture will be 45° . Mercury, therefore, requires less caloric, to raise it from 40° to 100° , than water; and, hence, water has a greater specific heat than mercury.

76. Specific heat, bears a near relation to what is called the *atomic weight* of bodies; since the product of one by the other is, generally speaking, a constant quantity.

77. LATENT HEAT.—The heat which is indicated by a thermometer is [51] called *sensible*; that which enters a substance, without raising its temperature is called *latent*.* If we add a large quantity of caloric to ice at 32° , or to water at 212° , while any ice remains in the former, or any water in the latter case, the temperature will not be raised:—because the ice was changed into water, which has a greater specific heat, than ice; and the water into vapour, which has a greater specific heat than water. The heat, thus rendered latent, was supposed by Black, to be chemically united with the water, and with the vapour.

78. Latent heat, is therefore, the result of a difference between the specific heat of the same substance, under different conditions. It arises from a wise provision of nature:—for if a large quantity of heat were not required, to change ice into water, or water into steam, the consequences would be, very often, highly inconvenient.

79. We can place our hand in high pressure steam, as it escapes from a boiler, &c., without any disagreeable effect, on account of the sudden and great expansion, and the consequent change of a large quantity of its heat, from the sensible to the latent state; but we would be scalded, by attempting the same thing with steam of low pressure—that, for example, which escapes from a tea kettle.

80. The steam, even from a concentrated solution of common salt—the presence of which raises the boiling point, as well as lowers the freezing point [48], of water—has a temperature of only 212° : because it immediately expands, in the atmosphere, and thus cools down until its temperature and elasticity balance the pressure of the air.

81. The heat, sufficient to melt ice would raise the same quantity of water through 140° :—hence the latent heat of water, in liquefaction, is 140° . And the heat required to change water at 212° , into steam of the same temperature, is 966° , or according to some, 967° .

82. The sum of the latent and sensible heat, is a constant

* *Lateo*, I lie hid. *Lat*.

quantity:—hence there is no economy in distilling at a low temperature.

83. EVAPORATION is the escape of vapour, without disturbing the fluid, whence it is produced. If the fluid were agitated, the effect would be termed *ebullition*, or boiling. Heat is the cause, both of evaporation, and ebullition. Some solids pass into vapour, without melting—thus iodine. Vast numbers of both solids and fluids, are perpetually giving off vapour, even at ordinary temperatures;—water, in the form of ice and snow, continues to evaporate.

84. Dr. Dalton inferred from his experiments, that the force of the vapour of all liquids is the same, at temperatures equally distant above or below the points at which they boil in the open air.—Hence, the elasticity of the vapour of mercury, in the *torricellian vacuum* [pneum. 31], must cause that fluid to be very slightly depressed, in the barometer, since its vapour, even at 212°, is only equal to that of water at -156°. It follows that the attraction of gravitation, acting on the particles of most solids and of many fluids, may easily counteract their tendency to fly off in vapour, at the temperatures of the atmosphere.

85. The opinion, therefore, is most probably erroneous, which supposes meteoric stones to be formed from the vapours of metals, &c., floating in the atmosphere and combined by electricity.

86. We may illustrate the elastic force of vapour, below the boiling point, by filling a glass tube, about three feet long and hermetically sealed at one end, with mercury: and inverting it in the same fluid. The *torricellian vacuum* [pneum. 31] will be formed in the upper portion of the tube: and, if we let up into this empty space a drop of any liquid, the mercury will immediately descend—and to an extent, proportioned to the amount of atmospheric pressure which will be neutralized by the vapour generated at the top of the tube.

87. The following is a table of the elastic force of the vapour of water, in inches of mercury, by Dr. Ure:—

Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.	Temp.	Force.
24°	0·170	115°	2·820	195°	21·100	242°	53·600	270°	86·300	295°	129·000
32	0·200	120	3·300	200	23·600	245	56·340	271·2	88·000	295·6	130·400
40	0·250	125	3·830	205	25·900	245·8	57·100	273·7	91·200	297·1	133·900
50	0·360	130	4·366	210	28·880	248·5	60·400	275	93·480	298·8	137·400
55	0·416	135	5·070	212	30·000	250	61·900	275·7	94·600	300	139·700
60	0·516	140	5·770	216·6	33·400	251·6	63·500	277·9	97·800	300·6	140·900
65	0·630	145	6·600	220	35·540	254·5	66·700	279·5	101·600	302	144·300
70	0·726	150	7·530	221·6	36·700	255	67·250	280	101·900	303·8	147·700
75	0·860	155	8·500	225	39·110	257·5	69·800	281·8	104·400	305	150·560
80	1·010	160	9·600	226·3	40·100	260	72·300	283·8	107·700	306·8	154·400
85	1·170	165	10·800	230	43·100	260·4	72·800	285·2	112·200	308	157·700
90	1·360	170	12·050	230·5	43·500	262·8	75·900	287·2	114·800	310	161·300
95	1·640	175	13·550	234·5	46·800	264·9	77·900	289	118·200	311·4	164·800
100	1·860	180	15·160	235	47·220	265	78·040	290	120·150	312	165·5
105	2·100	185	16·900	238·5	50·300	267	81·900	292·3	123·100	Another Exper	
110	2·456	190	19·000	240	51·700	269	84·900	294	126·700	312°	167·000

There is reason to suppose that the boiling point of water is lowered by the air which it contains. If entirely free from air—as when produced from ice melted under oil—it will not boil at a temperature lower than 275° . Steam will then be produced with explosive violence, and the temperature will immediately fall. When fluids are evaporated, vapour is given off quietly, as long as air is present in them : after which it is evolved in sudden bursts, that are often very troublesome.—It has been found that transmitting a current of air through them will prevent this inconvenience. If the surface of water, heated to 275° , is disturbed, steam of great force will be instantly liberated. There is little doubt that many steam-boiler explosions are in some way attributable to this cause.

88. A liquid communicates to solids, the power of being evaporated :—thus, boracic acid, which is *fixed* even at a white heat, evaporates sensibly along with the water in which it is dissolved. This property of fluids is a great source of loss, in the manufacture of salt ; and is, also, the reason why a storm, blowing from the sea, sometimes causes plants, thirty miles inland, to be covered with crystals of salt. It prevents mercury, &c., from being distilled, without some of the substances, with which they are united passing over likewise. It renders it impossible to obtain pure alcohol, by distillation :—for water rises with it, although the temperature is less than that required to distil water.

89. In obtaining the essential oils from plants, the oil passes over, along with the water with which it is necessary to surround them—to prevent an empyreumatic odour being communicated to the products. Without water these oils would require a much higher temperature for distillation. Sometimes it is necessary, even to raise the boiling point of the water, by adding common salt.

90. Evaporation produces cold :—hence, watering the streets, cools the air. In India, the tapestry of rooms and the blinds of windows are sprinkled with water, to cool the apartment. Persons wetted with rain, are injured by the evaporation, and consequent cold, which succeed. A rabbit may be killed, by the evaporation of ether from its surface. Mercury will be reduced to a very low temperature, by wrapping the bottle which contains it in cotton, and sprinkling the latter with ether. Prussic acid will freeze itself, by its own evaporation. A mixture of solid carbonic acid and sulphuric ether, produces a temperature of, at least, -166° , Fahrenheit, the lowest known.

91. Carnivorous animals feed, only at intervals :—for, as they do not perspire through the skin, less heat is carried off from them ; and, by consequence, less of their substance is required to be consumed in the production of animal heat. The cow,

&c., for a contrary reason, is obliged to eat almost continually.

92. It does not appear that evaporation is a chemical union between air and the fluid, since it is retarded by the presence of air.

93. Evaporation is sometimes applied to the production of intense cold. This may be illustrated by placing a small quantity of water under the receiver of an air pump, and along with it, in another vessel, some oil of vitriol—which, as we shall find hereafter, has a strong attraction for water. On exhausting the air, vapour will rise abundantly, and will be immediately condensed by the oil of vitriol;—the cold which results, will freeze the water. Also, if a thin bulb containing water is covered with cotton, when ether is dropped on the latter, and blown with a bellows, the water will freeze.

94. **THE DEW POINT.**—Air is capable of dissolving water; and the higher its temperature, the more it is capable of holding in solution. The dew point is that point of temperature at which the air would begin to deposit moisture. The nearer the air, at a given temperature, to the point of saturation, the higher its dew point.

95. **THE HYGROMETER*** is an instrument, intended to ascertain the presence, and measure the quantity of moisture contained in the atmosphere. It is constructed in many ways. Sometimes its action depends on the principle, that a substance increases in weight, and at others, that it increases in thickness and diminishes in length, by absorbing moisture.—A simple, and at the same time, a good hygrometer, is yet to be constructed.

96. The power which some bodies have of expanding, when they absorb moisture, is used for the purpose of splitting large, and very hard cylindrical blocks, into mill-stones. For this purpose, grooves are cut round them, at proper distances, and wooden wedges are driven into them:—during the night, the wedges absorb moisture, swell, and split the stone into the required number of pieces.

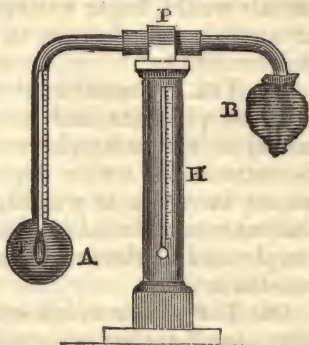
97. A very curious instance of the effect of moisture, in thickening and shortening ropes, &c., is on record.—The celebrated Egyptian obelisk was being erected, in front of St. Peter's at Rome, under the direction of the architect Fontana. But, after the most complicated, and effective machinery, had been constructed with the greatest care, it was found impossible to raise it quite to its destined position, on account of the ropes being a little too long. The architect, was, however, relieved from his perplexity, by some one in the crowd desiring “the ropes to be wetted:”—although, so important and

* *Hugros*, moist; and *metreo*, I measure. *Gr.*

so difficult was the operation considered to be, that all present were forbidden to speak, under pain of death. When this was done, the ropes contracted so much, that the work was easily accomplished. It is scarcely necessary to add, that the delinquent was pardoned, on account of the great service he had rendered.

98. *The wet bulb hygrometer.*—The rate at which water will evaporate, depends on the quantity of moisture in the atmosphere; for the nearer the latter is to the point of saturation, the less rapid the evaporation. The hygrometrical state of the air may be ascertained, with great accuracy, by finding the number of degrees, through which it must cool, before it reaches the dew point [94]. This is effected by the wet bulb hygrometer: which consists of two bulbs, A and B, fig. 301, connected by a glass tube. A small and delicate thermometer T is placed in A; and, along with it, some sulphuric ether; the whole is then hermetically sealed, the atmospheric air having been, as far as possible, previously removed from the tube, &c. On tying some muslin over B, and sprinkling it with ether, the evaporation and consequent cold, condense the vapour within:—this allows more to be produced, which [90] causes the thermometer inside, to fall. The point, down which A is cooled, at the moment that the moisture of the air, in contact with it, begins to be deposited upon it, indicates what should be the temperature of the atmosphere, in order that it should be just saturated, by the moisture which it contains.

FIG. 301.



99. The deposition of dew, on the glass of windows, arises from the air of the apartment—charged with aqueous vapour, by the breath of those within—being cooled, on account of contact with the glass, the temperature of which is lowered, by the coldness of the external air.

100. Dew is deposited on fine and bright nights, because the earth, which loses caloric by radiation [21], can receive none back again, as there are no clouds.

101. Rain will be caused, by a warm stratum of air, fully saturated with moisture, meeting a cold current.

102. The different capacity for moisture, of air at different temperatures, sometimes causes injury to the health.—When cold air enters the lungs, its temperature being immediately raised, its capacity for water [94] is increased. The consequence

of which is, that the lungs are deprived of their due quantity of moisture; and the accumulation of blood, from which a fresh supply is to be obtained, produces, but too often, the most fatal effects, by giving rise to consumption, in persons predisposed to that disease.

The same principles enable us easily to understand, the unhealthfulness of a very dry atmosphere, at higher temperatures.—Some, at least, of the dreadful properties of the sirocco, are due to its aridity. The dry air of March is dangerous to those whose lungs are weak:—and it appears cold, chiefly on account of the rapid evaporation, which it causes on the surface of the body.

103. In estimating the volume of a gas, it is necessary to take its hygrometric state into account. For, if it contains moisture, the pressure it exerts is made up of its own, and that of the vapour of water.

104. Whatever its hygrometric state, we may ascertain the space it would occupy, if it were dry, by “multiplying its pressure at the given hygrometric state, minus the pressure of the vapour of water at the same temperature [87], by the given bulk: and dividing the product, by its pressure at the given hygrometric state.”*

EXAMPLE 1.—When the barometer stands at 30 inches, 100 cubic inches of a gas are collected over water, at a temperature of 65°: what would be its volume, at the same pressure, if dry?

The pressure of the vapour of water, at 65°, is [87] 0.63 inches of mercury: and

$$\frac{30 - 0.63 \times 100}{30} = 97.9 \text{ cubic inches.}$$

105. We may ascertain how much a given quantity of dry air will increase in bulk, if saturated with aqueous vapour, by “multiplying its bulk, in the dry state, by the atmospheric pressure; and dividing the product, by the difference between the atmospheric pressure, and that of the vapour of water, at the same temperature. This will give us the bulk of the gas, in its hygrometric state;† from which, if we subtract its bulk in the dry state, we obtain the increase of bulk.”

EXAMPLE 2.—A gas which is perfectly dry, and at a tempera-

* Let M be its bulk, at the pressure of the atmosphere during the experiment, if it were dry: and M' its bulk, in its given hygrometric state. Let P be the atmospheric pressure, during the experiment: and P' this pressure minus the pressure of the vapour of water, at the temperature of the gas [87].—Sinc [pneum. 12] the pressure of a gas is inversely as its bulk,

$$P:P'::M':M, \text{ and } M = \frac{P'M'}{P}.$$

† Since [104: note] $P:P'::M':M$

$$M' = \frac{PM}{P'}$$

ture of 55°, amounts to 100 cubic inches when the barometer is at 30 inches; what would be its increase of bulk, if saturated with aqueous vapour?

The pressure of the vapour of water at 55°, is [87] 0.416. And

$$\frac{100 \times 30}{30 - 0.416} = 101.4 \text{ nearly.}$$

$101.4 - 100 = 1.4$ cubic inches, the required increase.

106. **EBULLITION** is caused by vapour which, being formed in the lower part of the vessel, disturbs the liquid as it ascends through it. We are enabled to construct, what is called a *water bath*, on account of the different boiling points of different fluids. For this purpose, the vessel from which the fluid is to be evaporated at a lower temperature than 212°—or which contains any substance, that must not be heated, beyond that point—is placed in a vessel of water, over the lamp, &c. It is evident that [77] the heat cannot exceed 212°. A temperature higher than 212° may be obtained, if necessary, by adding common salt, chloride of zinc, &c., to the water:—and when that fluid cannot be made sufficiently hot for our purpose, a bath of fusible metal [gal. 66] may be used for the purpose.

107. Altering the pressure on its surface, changes the boiling point of a liquid. For it cannot boil, until increase of temperature has given to its vapour an elasticity, sufficient to make it overcome the force that prevents it from rising—which force is the pressure on its surface. When the barometer stands at 30 inches, water boils at 212°, and ether at 100°; but *in vacuo*, water boils at 72°, and ether, at 44°.—Hence a liquid may boil, without being hot.

The ratio between the pressure and boiling point of a fluid, can be ascertained experimentally, or from tables [87].

108. It can be shown experimentally, that a fluid under reduced pressure will boil at a lower temperature, by boiling water in a flask, quickly removing the latter from the lamp, &c., corking, and then pouring cold water over it:—this will cause the water within it, again to boil. The, apparently strange, reproduction of ebullition, by the means of cold water, arises from the diminished pressure—caused by condensation of the vapour above the surface of the liquid—rendering the heat, which still remains, sufficient to make the water boil. The same thing may be effected, by removing the vapour with an air pump—the vessel containing the water, being placed under a receiver [pneum. 20]. If a large quantity of steam is suddenly withdrawn from a steam-boiler, the production of vapour which immediately takes place, is often extremely violent: and sometimes, it is probable, has led to steam-boiler explosions.

109. The pressure which affects the boiling point is not, in

reality, the pressure of the air, but that of the vapour contained in it:—since Dalton has shown, that gases and vapours offer no resistance to each other's elasticity. And, with a mixture of fluids, one may be evaporated, without another.—Thus when alcohol water and quick lime are placed under the receiver of an air pump, the lime will absorb the vapour of water, as fast as it is formed; while no more vapour of alcohol will rise, after a certain quantity has ascended into the receiver.

110. The difference of the boiling point, consequent on difference of pressure, gives us a means of estimating the height of mountains.—Every 530 feet, added to the perpendicular height of the place where water is boiled, lowers the boiling point one degree.

111. The fact that fluids boil at a lower temperature, under reduced pressure, has been applied to practical purposes, when considerable heat would be injurious. In sugar refining, for instance, to prevent the formation of treacle or uncrystallizable sugar, the vapour is drawn off as fast as produced.

112. When it is said that the boiling point is affected by the pressure on the surface of the fluid, it is supposed that there is a space in the upper part of the vessel, into which the vapour may rise.—If a very strong vessel is quite filled with water, it may be heated to redness. But, were the smallest space then allowed for the formation of vapour, the great heat would generate steam, which being of enormous pressure, would cause the most tremendous effects. This, in many cases, explains why steam-boilers have been burst, when, having been, either through neglect, or accident, quite filled with water, the steam has been turned on the engine, or the safety valve has been raised.

113. The nature of the vessel affects the boiling point.—Thus, when water boils in metal at 212° , it does not boil, in glass, at a less temperature than 214° . The smoothness of the glass vessel would seem an impediment to the formation of steam.

114. FREEZING MIXTURES depend on the fact, that substances lower their temperatures, when changed from the solid to the fluid state, if the caloric they contain is not, at the same time, increased so as to suit the change in their specific heat [75]:—that is, when the heat of fluidity is derived from the solid itself.

115. Thus, if salt and snow are mixed together, the latter will be melted, and [59] the zero of Fahrenheit will be obtained. The salt has a great tendency to unite with the water, which is not counteracted by the water being in a solid state.

116. Crystallized chloride of calcium possesses this tendency, in a still greater degree; and, when mixed with an equal weight of snow, it lowers the temperature from $+32^{\circ}$ to -51° . The chloride of calcium employed, should be crystallized: as the

crystals contain half their weight of water—which, being fluidified, augments the effect, considerably. To produce very intense cold, the substances must be previously cooled, and be made, by rapid mixture, to act upon each other, as speedily as possible.

117. The following are among the most effective freezing mixtures, containing neither ice, nor snow:—

Parts.		Cold produced.
Sulphate of soda, . 8	} Thermom. sinks from 50°, to	0 50°
Hydrochloric acid, . 5		
Sulphate of soda, . 3	} " " 50, to	-3 53
Dilute nitric acid, . 2		
Sulphate of soda, . 6	} " " 50, to	-10 60
Sal-ammoniac, . 4		
Nitrate of potash, . 2		
Dilute nitric acid, . 4	} " " 50, to	-14 64
Sulphate of soda, . 6		
Nitrate of ammonia, . 5		
Dilute nitric acid, . 4		

Mixtures containing snow, or ice:—

Parts.		
Snow, or pounded ice, 12	} From any temp., to	-25°
Common salt, 5		
Nitrate of ammonia, 5		
Snow, 7	} From . 32°, to	-30 62°
Dilute nitric acid, 4		
Snow, 1	} " . 0, to	-66 66
Crystallized chloride of calcium, . 2		
Snow, 2	} " . 32, to	-50 82
Crystallized chloride of calcium, . 3		
Snow, 3	} " . 32, to	-51 83
Potash, 4		

118. The most intense cold, yet obtained, is procured by evaporation of a mixture, containing solid carbonic acid and sulphuric ether, which gives a temperature of -166° , and according to some, of -180° .

119. Water is conveniently frozen, by pouring it into the small space between two cylindrical vessels of nearly equal size, one being within the other; the freezing mixture is then to be placed in the inner vessel, which should be of thin metal: and, having been rapidly stirred, for a short time, it may be removed:—after which, a hollow cylinder of ice will separate from the outer vessel, on turning it over.

120. When air is compressed, its temperature rises about 4° for every inch of mercurial pressure.—If, after being deprived of this sensible heat, it is allowed to expand in contact with water, the latter may be cooled down so as to be frozen.

CHAPTER XII.

THE STEAM-ENGINE.

History of the Steam-Engine, 1.—High and Low Pressure Engines, 7.—The Single, and Double acting Engine, 11.—Details of the Steam-Engine, 14.—Power, &c., of Engines, 55.—Expansive action of Steam, 66.—The Oscillating Engine, 69.—Rotary Engines, 70.—The Marine Engine, 87.—Locomotive Engines, 89.—Locomotive Engines, on ordinary roads, 98.—Atmospheric Railway, 99.—Proposed substitutes for Steam, 100.

1. HISTORY OF THE STEAM-ENGINE.—The steam-engine, as at present used, is but a recent invention. It is the result of the labours and ingenuity of many; but its perfection is due chiefly to Watt.

Hero of Alexandria, 120 years before Christ, described a machine which may be understood from fig. 302. It is very similar, in principle, to the reaction turbine [hyd. 128]. The escape of steam, from the apertures B and D, produces the same effect as that of the water, from E and H, fig. 162. This, which is not an economical application of steam, has often been re-invented.

FIG. 302.



2. In 1615 *Solomon de Caus* raised water, by condensing steam in a chamber which, by means of a tube, communicated with the water of a well:—the pressure of the air [pneum. 44] forced the fluid up, to supply the vacuum. In this case, a great waste of steam arose, from its being condensed until the surface of the chamber had acquired a temperature equal to its own.

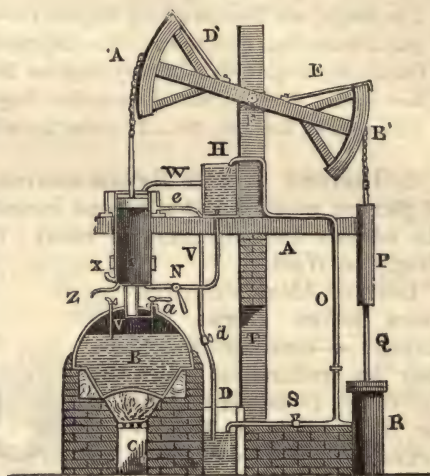
3. The *Marquess of Worcester* describes an engine, in which steam was made to raise water, by pressing on its surface. In this case, steam was wasted, in raising the temperature of the upper surface of the water.

4. *Savery* lifted water, by means of a vacuum produced by

the condensation of steam [2]; and elevated it still higher, by the pressure of steam on its surface [3]. He was the first to estimate the effect of steam, by comparison with horse power.

5. *Newcomen*, an ingenious blacksmith, raised water by an ordinary pump, which he worked by atmospheric pressure, obtained through the agency of steam. His, therefore, was an *atmospheric engine*. Its construction may be understood from fig. 303. A boiler B is

FIG. 303.



placed over the furnace C. A pipe leads from B, into the cylinder I:—the lower end of this pipe may be closed or opened, with a plate which fits it accurately, and is capable of being moved by a spindle, which passes steam-tight through the boiler, and has attached to it the handle *a*. The *injection pipe* N leads from the *injection cistern* H, which contains cold water, into the cylinder. The *eduction pipe* Z, at the opposite side, leads from the cylinder to the hot well. A small pipe X inserted into the side of the cylinder—near the bottom—and opening upwards, has its external aperture closed by the *snifting-valve*: so called, on account of the peculiar noise made by the air and steam, when escaping from it. A solid piston, which is seen in the upper part of the cylinder, is connected, by a rod and chain, with the *arched head* A'—fixed at one extremity of the beam A'B', turning on F. Another arched head B' carries a chain, to which is attached the *counterpoise* P, and the rod Q, belonging to the pump R—intended to raise water from the mine, &c., The arched heads A' and B', are strengthened by the iron rods D and E. Water, by means of the pipe W, is kept above the piston, to render it the more steam tight. The quantity of water in the boiler, is ascertained by a *gauge cock* V.

6. The counterpoise P, having raised the piston to the top of the cylinder, the steam-pipe is opened by the handle *a*. This causes steam to rush from the boiler, into the cylinder:—the air is driven out through the snifting-valve X: and the water, produced by the steam which was condensed in heating the cylinder, flows out through the eduction pipe Z. When

the assistant perceives that pure steam escapes from the snifting-valve, he closes the eduction and steam-pipes, and opens the injection cock N:—the water which rushes into the cylinder, condenses the steam: and, a vacuum is formed under the piston. The atmosphere then pressing upon the piston, causes it immediately to descend; and, the pump rod R being lifted, water is raised from the mine. When the piston has nearly reached the bottom of the cylinder, the injection cock N, is closed, and the steam-pipe is opened:—steam flows into the cylinder, as before: the air, which has been liberated from the water used for condensation, is blown out through the snifting-valve: and the condensed steam escapes through the eduction pipe. The counterpoise P, easily raises the piston, since the steam under it, has a somewhat greater pressure than the atmosphere above. A vacuum being again formed, the piston descends, and thus, the action of the engine is continued, at pleasure.

7. HIGH AND LOW PRESSURE ENGINES.—These terms, though very commonly used, are not accurate; since neither species of engine, necessarily requires the application of either high, or low pressure steam. We ought, rather, to say a *condensing*, or a *non-condensing* engine; since the peculiarity of its action, would then be accurately marked.

8. It is generally considered to be high pressure steam, when its force exceeds five or six pounds to the square inch—above atmospheric pressure. If the steam were employed, merely to form a vacuum, its force should be little greater than would be counterbalanced by that of the air outside, and it would have scarcely any tendency to burst the boiler. In expressing the pressure of steam, that part of it, which is neutralized by the atmosphere, is not taken into account.—Thus, when it is said to have a pressure of 10 lbs. to the square inch, in reality it has a pressure of 10 lbs. plus the pressure of the atmosphere. With non-condensing engines, a part of the pressure equal to that of the air is wasted, by the resistance which is offered to the passage of the steam from the engine to the atmosphere, after it has done its work: and the *effective pressure* will be that part only, which is above the pressure of the atmosphere.

9. The same amount of heat will convert the same quantity of water into steam, whatever may be the pressure on its surface: the only difference being, that the steam produced under high pressure will be less in bulk, and it will have more sensible but less latent heat.

10. The same quantity of water, converted into steam of any pressure, will produce the same mechanical effect. When its pressure is low, each cubic inch of it will have less pressure; but the number of cubic inches will be proportionably greater:

and the sum of the mechanical effects of all the cubic inches, whether their number is great or small, will be precisely the same. Hence, when bulk or weight is not important, there is no advantage in using high pressure steam—but the contrary: since, when very elastic, it is confined with greater difficulty, and the loss by leakage is more considerable. Also, in case of accident, the danger arising from it, is very great, which renders it necessary to use boilers, &c., of great strength. On the other hand, a condensing apparatus renders an engine larger, heavier, and more expensive in its original construction; and, in many cases, cannot be conveniently used.

11. THE SINGLE AND DOUBLE ACTING ENGINE.—Watt's *single* acting engine, like that of Newcomen [5], was an *atmospheric* engine:—its piston was depressed by the atmosphere, a vacuum being formed under it by condensation of the steam, and was raised by a counterpoise. It was found very difficult to regulate the power of the atmospheric engine, so as to make it accommodate itself to the different amounts of work to be done; and most injurious velocities were sometimes produced. The regulation was effected chiefly by diminishing or increasing the supply of water, by which condensation was produced. This diminished or increased the power of the engine.

12. In Watt's *double* acting engine, the piston was forced down by the pressure of steam above, a vacuum being formed beneath; and was raised by the pressure of steam below, a vacuum being formed above. Hence, this engine required no counterpoise to the piston.

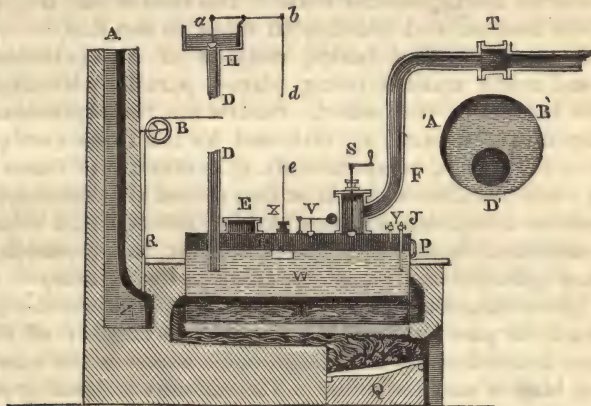
13. It is evident that the arched head cannot be employed to keep the piston-rod of the double acting engine perpendicular, during the stroke: since, on account of the flexibility of the chain, it is incapable of communicating an upward motion to the beam, when the piston is made to ascend.—Nevertheless the wear, and consequent leakage, arising from want of perpendicularity in the piston-rod, would be attended with very bad consequences. These difficulties were removed, by the beautiful contrivance, already described [mech. 295], and called “Watt's parallel motion.”

14. DETAILS OF THE STEAM-ENGINE.—We shall examine, successively, the various portions of the condensing engine, which differs from the non-condensing, only in having a greater number of parts.

The furnace, fig. 304, is so constructed, that all the air which escapes into the chimney, must pass through the fuel. A more rapid, and perfect combustion is thus secured: and the bottom, &c., of the boiler is not cooled, by a useless current of air. The bars are inclined a little, that the coal, &c., after being *coked*—that is, after having its gases expelled by the heat—

may fall inward with the greater facility. In well-constructed furnaces, a metal *coking plate* is placed just within the fire door: and the gases, there evolved, being mixed with the proper quantity of atmospheric air, pass over the fuel which is in a state of intense ignition, and are entirely consumed—particularly when the fire is properly stoked, the fuel being thrown in, by small quantities at a time. Any smoke which escapes from the chimney, is not only a nuisance to the neighbourhood, but a waste, also, of a very valuable portion of the fuel.

FIG. 304.



15. The draft of a chimney, arises from the difference between the weights of the column of rarified air within, and of the column of cold air without:—the greater the perpendicular height of the chimney, and the hotter the air within it, the greater this difference; and the greater, therefore, the draft.—Horizontal or oblique passages diminish the draft, by cooling the air, before it arrives at the effective portion of the flue. Sometimes, as in locomotives, the waste steam escapes through the chimney, being thrown up into it, by the *blast pipe*. The vacuum, thus caused in the flue, increases the draft: and, to the greatest extent, when the most intense fire is necessary—that is, when the engine is doing the largest amount of work. Should the fire burn more fiercely than is necessary, the draft may be diminished, by the *damper* which is hung over the pulley B by a cord or chain: so that, when let down, it closes the passage leading from under the boiler to Z.

16. Various contrivances have been devised, for increasing the *heating surface*—the object proposed being to make the hot air, before it escapes into the chimney, circulate, as much as possible, through or near to the water.

The mode in which heat is applied to the ordinary tea kettle—which may be considered as a boiler of extremely simple

form—is not economical. But in this case, economy is not the principal object; and the air which passes into the apartment is not, generally speaking, considered as absolutely wasted. Besides, the fire by which it is heated, must be adapted, also, to a variety of other purposes.

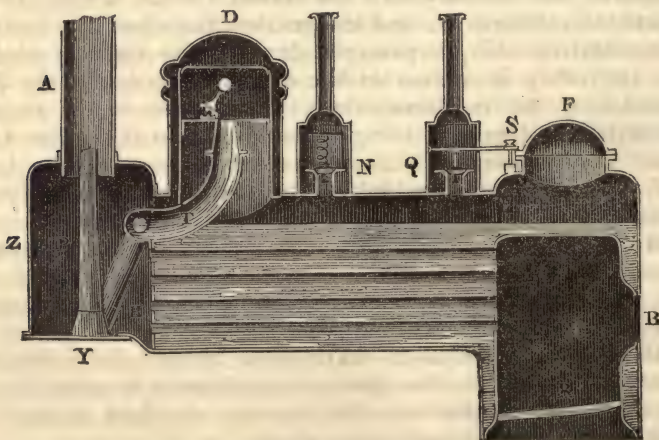
17. In setting boilers for washing clothes, &c., a certain attention is paid to effectiveness and economy. They are generally circular, and are *immersed* in the heated air—the furnace being closed in front.

18. The most simple ordinary form of steam-boiler, is a cylinder with hemispherical ends. The heated air, &c., passes under the bottom, and round both sides, to the flue.

19. A more efficient boiler, consists of two cylinders, the inner, and much smaller, being placed parallel with, and very near the bottom of the other. Such a one is represented by the longitudinal section, fig. 304, and by the transverse section A'B'D'. There is a, comparatively, thin stratum of water at the bottom: and the fire, which is at one end of the inner cylinder, is placed as low down as possible, for reasons that I have already explained [heat 17]. The heated air, &c., passes through the inner cylinder, and round the sides, to the chimney.

20. The arrangement is yet more effective, when the heated air is made to pass through the water, by a number of smaller passages, instead of by one large one: which is the case, with the best kind of marine boiler. The amount of heating surface is evidently much increased: since the sum of the surfaces of the smaller passages, is much greater than the surface of a single large one.

FIG. 305.



21. This principle is carried out still farther, in the boiler of a locomotive engine. B, fig. 305, is the door of the furnace or

fire-box:—the ignited fuel is entirely surrounded with water, except underneath, and at B. The heated air, &c., rushes through the tubes, with great force, into the *smoke-box* Z. The waste steam is conveyed by the *blast-pipe*, which is over Y, into the chimney A. When steam is generated with great rapidity, and in small spaces, it mixes with the water, so as to cause a foaming which is often very troublesome, and sometimes even dangerous. Water thus passes off along with the steam, and is a source of considerable inconvenience. To prevent this—which is termed *priming*, the steam is allowed to ascend into D, a higher part of the boiler called the *steam dome*: where, being in a state of comparative rest, it deposits the water: and, after being freed from it, passes down into the steam-pipe T.

22. There are two methods, by one or other of which, generally, the passage of the steam, from the boiler to the cylinder of a locomotive engine, is regulated. One of them, represented fig. 305, consists in opening or closing the steam-pipe T, by a slide which is moved with a rack and segment [mech. 289]—the latter being connected with a handle, &c., outside. The other, in the use of two circular concentric plates ground together steam-tight: each of them has two precisely similar apertures, which are nearly quarters of circles—openings, and spaces being placed alternately. When, by means of suitable mechanism, one of these discs is moved round, so that its apertures, to a greater or less extent, correspond with those of the other, a larger or a smaller passage is afforded to the steam. But, when the solid parts of one disc are placed so as to close the apertures of the other, it is retained in the boiler.

23. Cocks are generally used, in small engines, for putting on, or shutting off the steam; but, however well constructed, they, after some time, become leaky. When the engine is large, they are inapplicable: and the steam passage is opened or closed, by a metallic plate which slides over an aperture, and is moved by a lever, &c. Or a valve is lifted and depressed, by turning a screw.

The steam-pipe T, fig. 305, opens into passages which lead to the cylinders, supposed to be at Y.

24. Since the draft in a locomotive boiler is extremely powerful, cinders, &c., are carried, with great velocity, through the tubes; which are thus worn out very rapidly, and are a source of great and continued expense. They may be considered to be about sixty in number; and to cost £1 a-piece. They are made of brass—which is found, on the whole, to be the most economical: and are fixed in the circular apertures intended to receive them, by driving into each of their extremities hollow conical plugs of steel—that are easily cut, when they are to be

removed. If a tube bursts, during a journey, its extremities are stopped with wood, but little delay or inconvenience being caused by the accident.

25. Where a saving of space, and a rapid production of steam are still more important, as in the boilers of locomotive engines intended for experiments on ordinary roads, the form becomes yet more complicated.—Sometimes, in these cases, the boiler consists of a number of parallel plates, so united as to form alternate strata of hot air and water. With such an arrangement the hot air passes, in a very extended form and by a very circuitous route, into the chimney. This kind of boiler, and indeed every other which is of a naturally weak form, is strengthened by transverse bars of iron. The more a boiler progresses in effectiveness, the more expensive it becomes: because the more difficult to construct, and the more troublesome to keep in repair.

26. A large quantity of heating surface is essentially necessary to the rapid production of steam. Engineers, however, are not agreed as to the precise quantity; some consider that nine square feet, per horse power, are required.

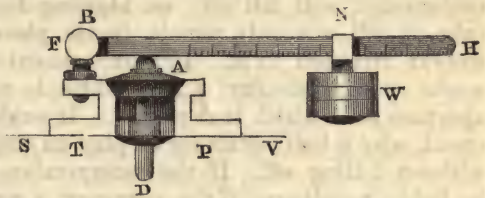
27. The interior of the boiler is divided into steam space, and water space.—If there is but little *steam space*, each stroke of the engine will, on account of the comparatively large quantity which flows into the cylinder, and the extent to which, therefore, what remains within the boiler has expanded, cause too great a variation of pressure [pneum. 11]. If, on the other hand, there is but little *water space*, the temperature will be too much lowered, by what is thrown into the boiler to replace the portion evaporated. Ten cubic feet of steam space, and the same of water space have been considered necessary. Some engineers however, think this too much, and others too little. The tubes of the boiler—if it have any—and a portion of the flue, should be *always* covered with water.

28. A proper water-level is maintained, in some cases, by a float, fig. 304, which is connected, by *e d b* and a lever *b a*, with a valve in the cistern H—placed at such a height, as will produce pressure [hyd. 8] sufficient to force the water into the boiler, in opposition to the steam. When the surface of the water descends the float falls, the valve in H is opened, and the proper supply flows down through DD—which must have 26·5 inches of height [pneum. 45], for every pound of *effective* pressure [8]. The proper quantity of water is thus maintained without any care on the part of the attendant. When the steam pressure is too considerable to allow of such an arrangement, or when, from any other cause, it is inapplicable, the boiler is supplied by a force-pump worked by the engine itself. In whatever way the water may be introduced, the pipe which conveys

it should descend almost to the bottom of the boiler, to prevent the steam from being condensed by a jet of cold fluid.

29. It is indispensable, that the quantity of water in the boiler, should be at all times easily ascertained. For this purpose, *gauge cocks* Y and J, fig. 304, are so arranged, that one of them, J, lets out steam, when there is too little water, and the other, Y, water, when there is too much of the latter. In many cases, the glass tube P, having cocks at each end, is used, as an additional security:—when both cocks are open, the water *ought* to stand in it, at the same height as in the boiler. Sometimes, even plugs of very fusible metal [gal. 66] are so placed, as to melt when the water becomes too low:—the escaping steam thus gives notice to the attendant, of the state in which the boiler is. But the same combination of the metals does not always melt at the same temperature; since they have a tendency to separate more or less, while cooling.

30. *The safety-valve.*—It is impossible to generate the steam, in precisely the required quantity. A means, therefore, of discharging it, when too abundant, is provided by the “safety-valve.” The principle on which it acts, will be understood from fig. 306.



DA, which is attached to the boiler SV, at TP, is made accurately to fit the seat at A: and is kept down, by the lever FH—having a fulcrum, at F, and weights W, at N. When the pressure, within the boiler, exceeds that which is upon the safety-valve, the latter, rises, and the steam escapes. The pressure may be increased or diminished, by sliding the weight along BH. Let, for example, that surface of the safety-valve which is within the boiler be two square inches: let the required *effective* pressure be 10 lbs. to the square inch: and, let the weight W be 5 lbs.—it is evident that [mech. 158] W must be moved out, until $FN=4FX$. Sometimes there is but one safety-valve: as, at V, fig. 304. Sometimes, for greater security, there are two: as, at N and Q, fig. 305—one of them being placed in such a way that the attendant, if he happens to be reckless of danger, cannot interfere with it.

31. It is found, occasionally, that the safety-valve adheres to the seat, so as to require a very large additional force to lift it:—hence, it should be raised a little, from time to time, that, as far as possible, it may be kept always ready for action. It is evident, that a slight change in the loading of the safety-valve,

will cause a very serious alteration in the total pressure within the boiler. And the consequences become, comparatively, more serious, when the boiler is constructed for low pressure steam: since the strain may easily become double, or triple what the boiler is calculated to bear.

32. In some instances, the safety-valve is affected by a cause which would scarcely be anticipated: and yet, it has, probably, given rise to some of those terrible explosions, the reasons of which, are not even conjectured. When the steam is escaping, it expands more and more, as it approaches the outer edge of the valve, since the space it occupies becomes, continually, enlarged:—it has even [heat, 79: and 108] a tendency to over-expand. The rarification which results, is equivalent to the production of a partial vacuum under a portion of the valve:—the atmospheric pressure upon it is, therefore, rendered more effective, since it is not counteracted beneath. This principle may be illustrated, by fixing at the end of a tube, a small circular plate having an aperture in the centre: and fitting to it a disc of card, &c., of the same size, but without any opening.—When the discs are laid together, and the tube is suspended vertically by the end which has no plate, the card, being underneath, will fall off; on blowing down, however, into the tube, it will not only remain in its place, but will support a weight attached to it. This experiment shows why a bellows works with difficulty, if the valve is much larger than the aperture over which it is placed. It enables us, also, to understand, why a ball continues to play on the water of a jet-d'eau, without falling off. If the safety-valve is very conical it will be liable to adhere; if the contrary, a partial vacuum will be produced:—the parts which come in contact with the seat should be made as small, as is consistent with the valve being steam-tight. It is evident that this valve, though indispensable, will not insure safety without constant attention. It should be so large as easily to permit the escape of all the steam generated by the boiler, if, from any cause, the engine is unexpectedly stopped. When too sudden a formation of steam occurs, there will not be time to overcome the inertia [mech. 6] of the safety-valve, which, therefore, cannot rise, and the boiler may burst.

33. It is proper to convey the steam from the safety-valve into a flue—or even into the water which is to be pumped into the boiler. Fuel is thus saved: and water, also, which is sometimes important.

34. The pressure of the steam within the boiler, if not too high, may be ascertained by a *mercurial gauge*:—every pound per square inch, above atmospheric pressure, will raise the mercury two inches, in the tube communicating with the boiler. If the pressure becomes very great, the mercury being blown out of the gauge, steam will escape.

35. When the furnace fire is removed—which may be effected very rapidly and conveniently, by causing the bars to drop down, their support at one end being withdrawn—the condensation of the steam, gives the atmospheric pressure a tendency to crush the boiler inwards. This is prevented, by a safety-valve opening in that direction. The use of such a valve is not confined to steam-boilers.

36. *The man-hole* E, fig. 304, and F, fig. 305, is an aperture, through which the workman enters, to clean the boiler, and remove a deposit which is formed by almost every kind of water: and which is not only very inconvenient, but even highly dangerous—since, being composed of an imperfect conductor of heat, it may allow the bottom to become red hot. The increased temperature would then cause it to crack: and water, passing through the fissures, would come in contact with the highly-heated metal, and be decomposed into its constituent gases—which occupy a very great space: or steam, of immense pressure, would be suddenly generated. In either case, the boiler would burst.

37. The sea water, used in marine boilers, would soon form a thick coating; but, before it is sufficiently evaporated to cause a deposit, the heavier portion—or that which contains the largest amount of salt, and which occupies the lowest place—is *blown out*, by a cock intended for that purpose, placed at the lower part of the boiler, and communicating, through the bottom of the vessel, with the sea. 10,000 grains of sea water contain about 253 grains of solid matter, of which about 220 grains are common salt. This “blowing out” is required, at intervals of a few hours. To save fuel, the water which feeds the boiler is sometimes heated by the pipe through which the brine escapes.

38. If, through neglect, the boiler is quite filled with water, no room being left for steam, a very high temperature [heat 112] will be produced: and, the safety-valve being opened—perhaps to prevent its adhesion [31]—a space will be afforded for steam. The latter is immediately generated, in small quantity, but of irresistible force—since a vast amount of caloric is suddenly imparted by the overheated boiler, &c.: and an explosion is the consequence. Should it be discovered, that the boiler is full of water, the fire ought, *at once*, to be extinguished.

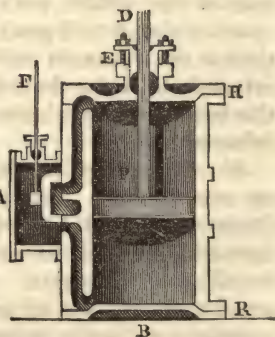
39. Boilers are constructed of various materials. Those which are employed for manufacturing purposes, have been made, occasionally, even of stone, or wood. In such cases, either the flame is thrown on the surface of the fluid, fire is made within it, or heated air is transmitted through it by flues. The imperfect conducting power of the stone, or wood, prevents the heat being wasted by radiation: but there is a considerable

loss, in other respects. Cast-iron boilers have sometimes been used for steam-engines; but they are extremely dangerous: since it is difficult to form them sufficiently strong:—and, should they happen to burst, their fragments are blown about, in every direction. The materials most generally applied to the purpose, are wrought iron, or copper—particularly the former. Copper is about four times as dear as iron; but it is twice as good a conductor of heat; and, on account of its uniform texture, it does not require to be near as thick as iron, though inferior to it, in tenacity [mech. 31]. There is not, therefore, so much difference in the cost, as might, at first, be supposed. Besides, an iron boiler, when worn out, is of but little value; while, one of copper will still bring a considerable price. Deposits do not form on copper, in a hard coherent mass—which diminishes the danger arising from them. Finally, if a copper boiler explodes, it merely opens; but one of wrought iron, is often blown to pieces.

40. *The steam-pipe and throttle-valve.*—F, fig. 304, also, T, fig. 305, is the *steam pipe*, which connects the boiler with the cylinder. The supply of steam is diminished or increased, according as the circumstances require, by the *throttle-valve* D, fig. 89 [mech. 284], which is connected with the *governor*.

41. *The cylinder.*—Steam passes from the steam-pipe, into the *steam chest* A, fig. 307. The rod F, moving steam-tight up and down, in a packing-box [heat 41], is connected with the *slide-valve*, which forms a communication between the atmosphere or condenser, and the upper or lower portion of the cylinder: and is worked by an eccentric [mech. 311], &c. The slide-valve, as represented in the figure, connects the upper part of the cylinder, and the middle—or, as it is termed, the *waste* port; and steam passes freely from the boiler, by the steam-pipe and steam-chest into the lower part of the cylinder: the *piston* P, therefore, is being raised. A little *before* the piston has reached the top of the cylinder, the slide-valve is shifted by the eccentric, so as to form a communication between the atmosphere or condenser, and the lower part of the cylinder: and, also, between the steam-chest and the upper part:—the piston P will then descend: and, in this way, it is made, alternately, to move up, and down. Since the inertia of the piston, &c. [mech. 6], prevents the steam from producing an instantaneous effect upon them, the eccentric is so adjusted, that the steam begins to act on the piston, before it reaches the top of

FIG. 307.



the cylinder; and, also, before it reaches the bottom:—this tends, also, to bring the piston, &c., more easily to a state of rest, before the motion is reversed. The extent to which the steam acts, in advance of the piston, is called the *lead* of the valve. If the solid part of the valve, at each end, is enlarged, so as to cut off the steam, before its motion upwards or downwards is stopped, the waste port still continuing to carry off the waste steam, the valve is said to have a *lap*. Various amounts of lap are allowed, in different circumstances. To facilitate the escape of the waste steam, the waste port and the passage leading from it, are twice as large as each of the steam ports and the corresponding passages.*

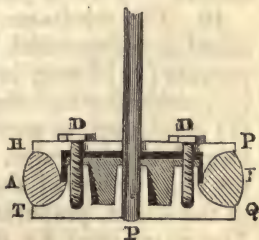
42. The steam, acting on the back of the slide-valve, forces it strongly against the surface over which it moves, and contributes, very much, to render it steam-tight. But the resistance thus caused to the motion of a large valve is enormous: and produces a serious waste of power—as may easily be conceived, from the very great pressure it sustains. If it consists, for example, of 100 square inches, the pressure upon it, at 40 lbs. to the square inch, will be 4,000 lbs.: which must generate great friction, and rapid wear. The pressure against the back of the valve is however, in some degree, counteracted by the pressure of the waste steam within it.

43. Sometimes, the steam is admitted *under* the valve, the latter being kept to its place, by a spring, &c. A, fig. 307, then communicates with the atmosphere or condenser.

44. There are many other kinds, besides the ordinary D,* or slide-valve: but it is the most generally employed, being extremely simple, convenient, and effective. *The eccentric*, by which the valve is worked [mech. 311] is generally keyed on the crank axle.

45. *The piston* must fit the cylinder with great accuracy, to prevent the escape of the steam from one part of it to the other, which would cause a waste of power: and it must be so constructed as that, notwithstanding the wear and tear, it may *continue* steam-tight. This is effected by a hemp, or a metallic packing. When the former is used, hemp, platted in a particular way and termed *gasket*, is kept constantly pressed against the interior of the cylinder. The piston-rod P, fig. 308, is keyed, &c., into lower plate TQ: the upper one HP, is movable on the piston-rod, and is capable of being forced nearer to TQ, by means of screws

FIG. 308.



* So called from the shape of its longitudinal section.

D, D, &c., so as to compress the ring of gasket A T, and force it outwards.

46. Hemp, however, though in many respects very convenient, has been generally superseded by *metallic packing*. This is formed in various ways. Sometimes metallic rings, turned with great accuracy and cut into segments R, P, and Q, fig. 309, are placed between plates corresponding to H P, and T Q, fig. 308. Triangular pieces E, F, and H, also formed with great care, are placed in the angles made by the contiguous segments: and are pressed outwards by a spring, which is somewhat like a hoop, and is in contact with all of them. As the segments become worn, they and the triangular pieces are forced out by the elasticity of the spring, so that the piston remains steam-tight, and even improves, by use. Sometimes, the same piston contains two or even more rings cut into segments, the vertical joints of one being placed between those of another.

FIG. 309.



47. The packing of a piston often consists of a ring, like that represented by N, fig. 309. It is of varying breadth, and is cut in only one place. An angle piece B, is kept in its position by a spring D, having a screw in the centre. On account of its peculiar form, the elasticity of the ring causes it to press evenly in all directions, against the cylinder: and it is introduced into the latter, by bringing the ends forcibly together, so as to diminish its size. More than one ring of this kind, also, is used for greater security [46].

48. A packing-box, placed on the cover of the cylinder, causes the aperture through which the piston-rod passes into the atmosphere to be perfectly steam-tight. Sometimes the *gland* which compresses the packing round the piston-rod, is made to act merely by its own weight, without any screws:—a constant and uniform pressure is thus obtained. The piston-rod, also, is sometimes rendered steam-tight by a metallic, instead of a hemp packing.

49. *The condenser*.—The piston of a condensing engine is raised and depressed, alternately, by steam from the boiler: a vacuum [12] being, in each case, produced at the opposite side, by condensing the steam, which rushes with great velocity into the condenser, as soon as the proper communication has been formed by the valve. The retardation of motion, at and near the dead points of the crank, affords time for the condensation of the steam, preparatory to the reversed motion of the piston. The water used for condensation, flows into the condenser, in the form of a jet; and the quantity required for the purpose, may be easily calculated.—If the latent heat of water changed

into steam, is considered as 966° [heat 81], 26·95 cubic inches of water at 60° will, by condensing steam at 212°, become 27·95 of water at 100°.*

50. The steam was, at first [5], condensed in the cylinder itself. But this method was abandoned by Watt, on account of the waste, arising from the loss which arose from so often heating such a large mass: and he employed a separate vessel, for the purpose. The condenser is kept at as low a temperature as possible, by immersion in cold water—which is replaced, as it becomes heated, by means of a pump worked by the engine. The warm water, being specifically lighter, rises to the top [heat 17], and flows away through a waste pipe—so placed that a constant level is maintained. The condensed steam and condensing water, should not have a higher temperature than 100°:—if they were at 212°, steam would be formed in the condenser, and, pressing against the piston, would retard its motion.

51. To avoid, as much as possible, the use of salt water, which, on account of the deposit it forms [37], and for other reasons, is very inconvenient, several plans have been proposed, for producing a vacuum by cooling the condenser, externally. But, from the necessity of exposing a sufficiently large surface of steam to the action of the cold, it is difficult, in this way, to effect the condensation, with sufficient rapidity—particularly without a complicated apparatus. Hall's condenser, intended for the purpose, consists of a very extended series of pipes immersed in cold water. Such a contrivance was employed by Watt. When it is used, the air pump may be smaller, as no air will then be removed by it—in which case its name will no longer be appropriate. Watt, however, abandoned the tubular condenser, on account of its not producing the condensation with sufficient rapidity. He also found a kind of fur to collect in the pipes, which, unless frequently removed, prevented the heat of the steam from passing quickly to the water outside.

52. The vacuum in the condenser, is often indicated by a barometer gauge similar to that which I have already described [pneum. 33].

53. *The air pump.*—The condensed steam, condensing water, and the air disengaged from the latter when its temperature is raised, are drawn off by what is called the “air pump:” and are discharged into a reservoir from which the boiler is supplied, and which is termed the *hot-well*. If a float, fig. 304, [14] cannot be conveniently used, water is pumped into the boiler, directly from the hot-well. But as the latter would supply twenty-eight times [49] as much as is required, the excess passes off by a waste pipe.

* It must be changed, from 1178° (212+966) to 100°, by water, each cubic inch of which takes 40° (100—60). But $1078^\circ \div 40 = 26\cdot95$.

56. In estimating the power of a steam-engine, some unit or standard of comparison must be employed. Watt selected as such, 33,000 lbs. raised one foot high per minute: because he considered that to be the effect producible, on the average, by one horse: and it has been universally adopted, by engineers. Since, [mech. 149] different horses, in the same circumstances, and the same horses in different circumstances, would perform very different quantities of work, any estimate of the kind must be, to a certain extent, arbitrary:—but whether correct, or otherwise, it will answer equally well for comparing engines with each other, &c. It has been supposed, that a horse produces a maximum effect, when travelling at the rate of $2\frac{1}{2}$ miles per hour, or about 220 feet per minute. And this, without any sufficient reason, has been very generally taken as the best speed for the piston of a steam-engine: although the velocity with which it moves, ought, in some measure, at least, to depend on the use to which the engine is applied. Few horses would raise 33,000 lbs. one foot high per minute, working eight hours per day;—but, supposing it to be their average effect, one horse power may be considered as equivalent to three horses, since the engine can work, if necessary, twenty-four hours—with a proportional consumption of fuel.

57. To find the horse power of any engine, “multiply the number, expressing in pounds the pressure per square inch on the boiler, by the area of the piston in inches: then the product, by the space in feet, which is traversed by the piston during each stroke; after which multiply this result by the number of strokes per minute, and divide what is obtained by 33,000.”

EXAMPLE.—An engine makes 50 strokes per minute; the diameter of the cylinder is 9 inches; the length of the stroke 2 feet 3 inches; and the pressure on the boiler 25 lbs. to the square inch. Required the horse power.

25 , the pressure in lbs.

multiplied by 63·6174,* the area of the piston in inches,

give 1590·435, the pressure on the piston in lbs.

Multiplying this, by 4·5,† the number of feet, traversed per stroke,

we obtain 7156·9575 lbs. raised one foot high, each stroke.

Multiplying this by 50, the number of strokes per minute,

we obtain 357847·875 lbs. raised one foot high per minute, and $357847·875 \div 33000 = 11$ horse power, nearly.

58. The diameter of the cylinder may be found, when the other conditions are given, “by multiplying the pressure, in pounds, by the number of feet traversed in each stroke, and the product by

* The square of the diameter, multiplied by 0·7854.

† The piston travels backwards and forwards, each stroke.

the number of strokes; then dividing the result into the product obtained by multiplying together 33,000 lbs. and the number expressing the horse power:—this will give the area. Dividing the latter, by 0·7854, and taking the square root of the quotient, will give the diameter in inches.”*

EXAMPLE.—An engine is to make 45 strokes per minute; the length of the stroke must be 22 inches; the pressure per square inch 31 lbs.; and it is to be 8 horse power. Required the diameter of the cylinder.

31, the pressure in lbs.
multiplied by 3·6666, the space traversed per stroke,
give 113·6646. Multiplying this
by 45, the number of strokes per minute,

we obtain 5114·907, which divided into

264000 (8×33000) gives 51, nearly. But $\sqrt{\frac{51}{0\cdot7854}} = 8$, nearly, the required diameter in inches.

59. To find the length of stroke, “multiply the number expressing the horse power, by 33,000: divide the result, by the product of the pressure per square inch in pounds, the area, and the number of strokes: then divide the quotient by 2.”†

EXAMPLE.—An engine is to make 35 strokes, per minute; the diameter of the cylinder must be 18 inches; the pressure per square inch 40 lbs.; and it is to be 51 horse power. Required the length of stroke.

$$\begin{aligned} 51 \times 33000 &= 1683000. \\ 40 \times 254\cdot47 \text{ (the area)} \times 35 &= 356258. \\ \text{and } \frac{1683000}{356258} &= 4\cdot7, \text{ nearly.} \\ \text{and } \frac{4\cdot7}{2} &= 2 \text{ feet } 4 \text{ inches.} \end{aligned}$$

The length of a well-proportioned cylinder, is about twice its diameter:—the greater its length, the greater the obliquity of the connecting-rod. Sometimes, as in marine engines, circumstances require the cylinder to be very short, considering its diameter.

* Let P be the number expressing the horse power; p , the pressure in pounds, on a square inch of the boiler; a , the area of the piston in inches; d , the number of feet traversed in each stroke; n , the number of strokes; and w 33·000 lbs. Then [57]

$$P = \frac{padn}{w} \text{ and } a = \frac{Pw}{pdn}$$

$$\text{But the diameter} = \sqrt{\frac{a}{0\cdot7854}}$$

† Since [57] $P = \frac{padn}{w}$, $d = \frac{Pw}{pan}$. But the stroke = $\frac{d}{2}$

60. To find the number of strokes “multiply the number expressing the horse power by 33,000 : then divide the result, by the product of the pressure in pounds, the area, and the space traversed per stroke.”*

EXAMPLE.—The cylinder of an engine is to be 15 inches in diameter : the stroke is to be 31 inches ; the pressure 24 lbs. per square inch ; and it is to be 14 horse power :—what must be the number of strokes, per minute ? The area of the piston is 176·715 ; the space traversed each stroke is 5·1 feet. And

$$\frac{14 \times 33000}{24 \times 176 \cdot 715 \times 5 \cdot 1} = 21, \text{ nearly, the required number of strokes, per minute.}$$

61. To find the pressure per square inch, “divide the product of the number expressing the horse power and 33,000, by the product of the area of the piston, the distance traversed by the latter during a stroke, and the number of strokes per minute.”†

EXAMPLE.—The number of strokes, to be made by an engine, is 27 ; the diameter of the cylinder must be 37 inches ; the length of the stroke 76 inches ; and the horse power 100 :—what must be the pressure, per square inch ? The area of the piston is 1075·2126 inches ; the distance to be traversed by the piston, during each stroke, 12·7 feet :—and

$$\frac{100 \times 33000}{1075 \cdot 2126 \times 12 \cdot 7 \times 27} = 9 \text{ lbs., nearly.}$$

62. It is to be remembered that, in calculating as above, the loss of force which arises from various causes—and makes the effective very different from the nominal horse power of the engine—have not been taken into account. The steam, having been heated in contact with water, it cannot have its temperature reduced, without suffering partial condensation : for, none of its pressure arises from its having been expanded, while in the gaseous state. Loss of power, therefore, is caused in this way by radiation, during the passage of the steam from the boiler to the cylinder. There is a loss of the steam which is in the passages, when a communication between the cylinder and atmosphere, or condenser, is opened : and also of that, however small, which is between the piston and end of the cylinder, when the motion of the former is reversed. The steam, thus unavoidably wasted, is called the *clearance*. Steam is wasted, also, to a greater or less extent, by leakage.

In addition to all this, power is expended in overcoming the

* Since [57] $P = \frac{padn}{w}$, $n = \frac{Pw}{pad}$

† Since [57] $P = \frac{padn}{w}$, $p = \frac{Pw}{adn}$

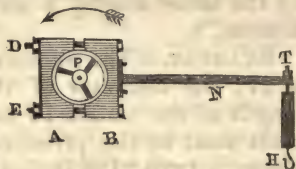
friction of the piston against the cylinder, and that of the various joints, &c. : likewise, in working pumps, &c.

63. Every cubic inch of water, changed into steam, ought, to raise one ton, a foot high : and, as one horse power or 33,000 lbs. is nearly 15 tons, 15 cubic inches of water per minute, or 900 per hour—but little more than half a cubic foot—ought to give one horse power. But, in reality, the quantity allowed by engine manufacturers, is from one to two cubic feet : that is, from twice to four times as much, as would be required, if the entire force, produced by it, were effective.

64. It is very difficult to estimate the power of an engine, from the work which it does. The only unobjectionable mode of testing it, is with a friction brake, something like AB, fig. 311, fixed on a drum attached to the crank-axle, &c., and connected with a spring balance HT.

FIG. 311.

When the brake, which is of wood, is tightened on the drum, so as to bring down the speed of the engine to its rate, when doing a maximum amount of work, the indication of the balance is noted. Let us suppose, for example, that from the centre of the drum P, to the place where T is attached, is six feet. Every pound of pressure, indicated by the balance, is equal to one pound, raised through 36 feet—the space equivalent to a circle of six feet radius. If this is multiplied by the number of pounds—adding, or deducting, as the case may be, the weight of the brake itself: and the product, by the number of revolutions: the result, divided by 33,000 lbs., will be the *real* horse power.



65. The relative consumption of fuel, is quite independent of the power of an engine; and is modified, by the construction of the furnace, &c. The quantity which should be allowed, per horse power, has been variously estimated. In marine engines, it has been found to vary, from seven to twelve pounds, per hour. A pint of water may be evaporated by two ounces of coal: and it will form 216 gallons of steam, which should raise 37 tons, one foot high. A pound of coke, in a locomotive boiler, would evaporate about five pints of water: and the steam generated would easily draw two tons, one mile, in two minutes.—Four horses under a stage coach, would take six minutes, to do the same thing. The Menai suspension bridge is 560 feet, in span, 100 feet above high water mark, and contains 2,000 tons of iron:—except for the waste of power caused by friction, &c., it might be lifted to its present position, by the consumption of about four bushels of coal. The four great central tubes of the Britannia bridge, are each 472 feet in length, and about 1,800 tons in weight:—all of them should be raised to

their present height, the same as that of the Menai suspension bridge, with about 15 bushels of coal. The materials of the great pyramid of Egypt, which, according to Herodotus, required for its construction 100,000 men during 20 years, and weighs 5,696,428 tons, ought to be placed where they are, with the steam generated by the consumption of about 480 tons of coal.

66. EXPANSIVE ACTION OF STEAM.—When the piston, &c., are to be put in motion, more force is required, on account of inertia, than afterwards. The velocity will, therefore, be accelerated; which, besides other inconveniences, makes them be stopped, with greater difficulty. The advantage of working the steam expansively, as a means of gradually bringing the reciprocating parts to rest, and, also of obtaining a great additional power from it, soon suggested itself to Watt. When the piston has reached the bottom of the cylinder, the elasticity of the steam is diminished, but not destroyed:—it still tends to expand. If then, it is cut off, for example at half stroke—that is, if communication with the boiler is suspended as soon as the cylinder is half filled, the expansive power will continue to move the piston: and, with a force which decreases at such a rate that, when the steam shall have expanded, so as to fill double the space, the piston will be acted upon [pneum. 11], by half the original pressure. For, steam, as long as it remains in the form of an elastic fluid, follows, so far as its mechanical properties are concerned, the same laws as atmospheric air. All the force, obtained from the steam, while expanding, is so much power gained: and the sooner communication with the boiler is cut off, the greater the advantage. Let steam, having a pressure of 60 lbs. to the square inch, be cut off at half stroke—the whole stroke being two feet, and the surface of the piston being 150 square inches. During the latter half of the space traversed, the piston is impelled, with a force uniformly decreasing from 60, to 30 lbs.—which is the same as if it had been urged, through the whole time of expansion, with a force of 45 lbs. $\left(\frac{60+30}{2}\right)$. But $150 \times 45 = 6750$:—that is 6,750 lbs.

raised one foot. And, supposing the number of strokes to be 50 per minute, $50 \times 2 \times 6750 = 675000$ lbs. are raised one foot high in that time:—and, by means of a force, which is obtained without any additional expenditure of fuel, and which is equal to about two-thirds of what is derived from the steam, before it begins to expand. It may easily be found, by calculation, that cutting off the steam still earlier in the stroke, would increase the gain.

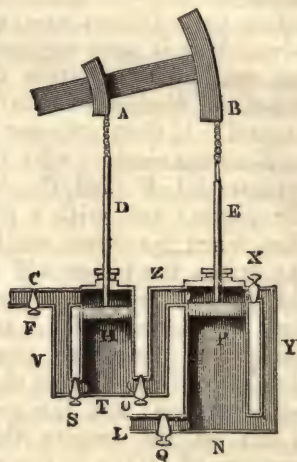
67. When steam is used expansively, the details of the engine must be somewhat modified.—If a *slide-valve* is employed, it must receive two motions, while the piston moves in the same

direction; the first should make the ports communicate, respectively, with the condenser or atmosphere, and the boiler; the second must close the communication with the boiler at the proper time, that with the condenser or atmosphere being left open. The *lap* of the valve [41], which causes the steam to be cut off, before the end of the stroke may, according to its quantity, be applied within certain limits, to produce a greater or less expansion. Sometimes the steam is cut off by a separate slide, worked by an eccentric, or otherwise.

The governor [mech. 284] is occasionally used to regulate the amount of expansion.

68. *Hornblower's engine*.—The steam was allowed by Watt, to expand, in the ordinary cylinder. But it was supposed by Hornblower, that it would be advantageous to add a second, for this purpose. A, and B, fig. 312, are arched heads, fixed on the great working beam: H, and P, are cylinders of such dimensions that, when the beam is raised or depressed, the pistons will just reach to the upper or lower extremities of both. At the commencement, all the cocks C, S, O, &c., are opened, that steam may, by blowing through, expel the air. All are then closed, except the exhausting cock Q, and the steam cocks F, and O:—this causes steam to press on the lesser piston: and, a

FIG. 312.



vacuum to be formed in the lower part of the greater cylinder, the piston of which will be pressed down by steam passing through Z, from the lower part of the lesser cylinder. As the steam in H expands, the piston above it will be pressed down with an increasing force: while, on the other hand, as the steam above the greater piston expands, its force will diminish:—and, thus, a nearly uniform power will be obtained. At the end of the stroke, a free communication is opened, between the upper and lower portions of the smaller cylinder, by turning the cock S; and between the upper and lower portions of the larger, by turning X: and the pistons, being indifferent to motion in either direction, are both raised by the counterpoise, preparatory to the next stroke.

The use of an additional cylinder has not been attended with the advantage expected.

69. THE OSCILLATING ENGINE was devised as a means of avoiding the loss of power, arising from the obliquity of the

connecting rod [mech. 299]. In this engine, the piston-rod F, fig. 313, acts *directly* on the crank NE; and the cylinder H, to accommodate itself to the different positions of the latter, moves backwards and forwards, so that its extremities describe arcs of circles around the *trunnions* or hollow pivots on which it rests. These trunnions, respectively, admit the steam to the cylinder, and afford it a passage to the atmosphere or the condenser, after it has done its work. The force which, with all the ordinary kinds of engine, is expended, in bringing large masses of matter, alternately to a state of rest and motion, becomes very considerable with this: and it is difficult to keep it from working loose, on account of the great strains in opposite directions.

The trunnions are, sometimes, placed on other parts of the cylinder.

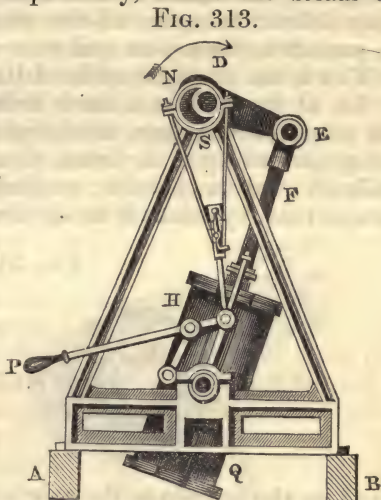


FIG. 313.

70. ROTARY ENGINES.—Under this head, strictly speaking, are included all machines which are intended, either directly or indirectly, to produce a rotary motion by the force of steam;—but it is generally restricted to those, with which it is obtained more or less directly.

71. The earliest rotary steam engine, of which we have any account, was that of Hero—which I have already described [1].

72. Steam has been applied to the *direct* production of rotary motion, by a variety of contrivances founded on very similar principles. I shall content myself with giving an idea, only of what I consider

the most remarkable. A, fig. 314, is a fixed hollow cylinder, bolted, firmly, in its place: P, a piston, which revolves round F, and carries along with it a small

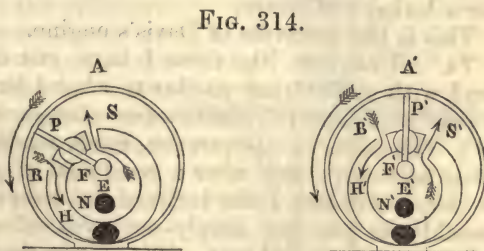


FIG. 314.

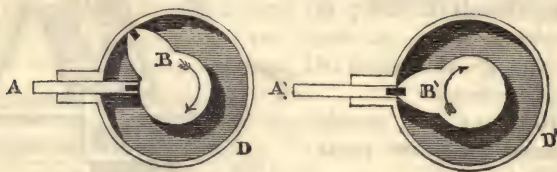
double cylinder, through which, by means of a longitudinal opening, it slides steam-tight. The steam enters the engine, at N, and passing out into S, presses on the adjacent side of P,

moving it round in the direction of the external arrow. The waste steam passes from B, into H: and escapes, through an aperture, seen in the latter. A' shows P, in another position.—It is evident that there will be a *dead point*, when P is passing the lowest part of A. This, however, may be remedied, by using a fly-wheel, or a second engine. It must, obviously, be very difficult to render all the working parts steam-tight; and to provide against wear and tear.

This is the principle of Lord Dundonald's engine.

73. D, fig. 315, is a fixed hollow cylinder, bolted firmly in its place; B, revolves steam-tight, in A. E is a slide, which, being pushed up to B, forms, along with it, a steam-tight compartment, in the cylinder; and which, being withdrawn at the proper time, by means of the species of eccentric, termed a cam—

FIG. 315.



fixed on the outside to the axle, on which B revolves—allows H to pass. When steam is admitted into one compartment of the cylinder, and, at the same time the waste is allowed to escape into the atmosphere or condenser from the other, B will revolve, as also, the axle and any machinery attached to it. There is a *dead point*, while the projection on B is *actually* passing A; but the inconvenience is obviated, in the same way, as with the engine last described. D' represents B, at the dead point. The principal difficulty connected with this engine, is that of keeping the ends steam-tight, and the withdrawing E precisely at the proper time, so that there shall be neither a useless resistance, nor a leakage of steam.

This is the principle of Davis's engine.

74. All engines, like those I have just described, must contend with difficulties, similar to what I have already noticed, when I explained the construction of an eccentric pump [pneum. 51]. Though, in appearance, easily made, they require very great accuracy: and, after a good deal of *practical* experience in these matters, I am inclined to believe, that it is hardly possible to provide simply—or even effectively—against the subsequent wear and tear. It is certain that, with such engines, a considerable loss may arise from friction or leakage, without its being detected by a mere casual observer. The longer the parts of a common reciprocating engine, work together, within

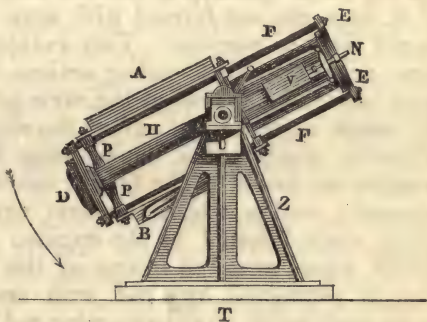
reasonable limits, the better they will become, as their surfaces will adapt themselves the more perfectly to each other.

75. In the ordinary engine, there is a great loss of power, arising [mech. 299] from the obliquity of the connecting rod, and the force uselessly expended in bringing heavy masses so often from rest to motion, and *vice versa*—both which are inseparable from it. Its details, however, are excellent: while the defects essential to rotary engines, as usually constructed, appear to be insuperable.—These considerations induced Mr. Allingham, of this city, and myself, to undertake, conjointly, a long and costly series of experiments, for the purpose of applying the ordinary piston, cylinder, slide-valve, &c., to a rotary steam-engine.

76. The plan we adopt, will be understood from fig. 316.

FIG. 316.

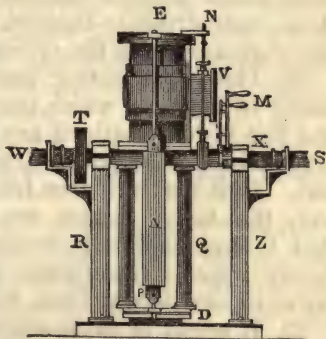
A cylinder, of the usual form, is bolted to a strong square plate, which is cast on an axle: and contains the packing-box through which the piston-rod passes. The cross-head PP, attached to the piston-rod—concealed by the pillar H—works up and down guide bars FF, and carries weights A and B. These



weights are connected with F and F, by eyes which are fixed on their other extremities, and which correspond exactly with the ends of the cross-head: so that when the piston is raised, by the steam, twice each revolution, the weights move easily, but steadily, along the guide bars. Each of the latter is fastened

FIG. 317.

at one end, to the cover of the cylinder, and at the other to D, which, with pillars—one of which is seen at H—counterpoises the cylinder, and, at the same time, forms an efficient framework. F and F are—for the sake of greater strength—connected, at their centres, with the strong square plate, attached to the axle. V, is the steam-chest; N, the valve-rod. The whole revolves on pedestals, one of which is seen at Z. The steam is admitted, by one extremity of the axle: and the waste passes out, by the other. Fig. 317 represents this engine in a position at right angles to the former.



77. It is evident that the effect is obtained, through the medium of gravitation. The principle has occurred to many persons long since, and, among others, to Watt; but the difficulties attending it seem to have, hitherto, prevented its application. The most serious of these is the necessity of bringing large masses of matter, gently, and with certainty, into alternate rest and motion. This is done, in the ordinary engine, chiefly, by means of the crank; and any strain, or loss of power, which may occur, is not at once detected. If the weights A and B, fig. 316, are stopped by solid matter, most violent concussions will be produced: and springs would cause a very inconvenient vibration. The object is, however, attained, by cutting off the steam, at a proper part of the stroke: and destroying any small quantity of motion, which *may* remain at the end of it, by a cushion formed with some of the waste steam, retained for the purpose. Two independent, but, at the same time, perfectly corresponding actions, are required.—The ports must always be opened at the same period of revolution; and the steam must be cut off at the same part of the stroke, in whatever position the engine may happen to be, when the weights are raised. The former condition is secured by a *fixed* eccentric, within which the axle revolves—its ring or strap being carried round by the engine: and the latter, by an inclined plane, attached to one of the weights. The eccentric ring is connected, by a rod, with one extremity of the small cross-head which works the valve rod: and the inclined plane, by a bell crank and a rod, with the other:—each end of this cross-head constitutes a fulcrum, when the other is moved.

78. By this arrangement, the steam acts, invariably, in the direction in which it is intended to produce effect; and, therefore, the loss due to the obliquity of the connecting-rod is avoided. There is no diminution of power, from the portion of waste steam which is retained, since it helps to fill the cylinder, at the next stroke:—besides, it has had, at least, the same facility of escape, as in the ordinary engine.

79. The reciprocating parts are brought to rest, independently of rotation, which prevents irregularity of motion, &c.: and this is done, without any consumption of steam, since what is retained for the purpose, being still in the cylinder, is not lost. It is perfectly free from noise, concussion, or vibration: and, the heavy masses are stopped, with such gentleness, that I have habitually worked an engine of about two horse power, which I constructed myself, with the axle merely resting on its bearings, and not, in any way, confined from above.

80. It might be supposed that the weights A and B, fig. 316—always, either at one side, or the other, of the centre of motion—would give rise to more or less vibration: but this is not

the case. There is an important difference between a weight, which is attached, for example, to the rim of a fly-wheel, being made to revolve by the wheel, and being itself the cause of the wheel's motion. In the former case, there will be vibration, from a tendency in the weight to remain behind, on account of its inertia [mech. 5]; while there will be none, in the latter.

81. The weights required, will be found, on making the calculation, comparatively trifling. And the whole engine will not weigh more, nor occupy a larger space, than the fly-wheel of an ordinary engine having the same power. Unlike the latter, however, when its various parts are made massive, they are not only stronger but are more effective whether they constitute a source of motion, or, from acting as a fly [mech. 254], a means of regulation.

82. There is no loss of power, on account of one portion of the weights counteracting the effect of the other.—Their common centre of gravity is raised through a certain space, twice during each revolution: and it must fall through exactly the same distance, before it can be again raised. During their fall, they act on the machinery, like water in the buckets of an over-shot wheel [hyd. 109].

83. Neither does any loss arise, from centrifugal force; for, if it renders greater steam pressure necessary, before the centre of gravity of the weights has reached the centre of motion, it causes less to be required, when it has passed that point. Moreover, the greater the centrifugal force, the more expansively [66] the steam is used: for the piston *outruns* the steam, when its velocity is such, that there is not time, for the space behind to be filled up. And with reasonable velocities, the centrifugal force is never inconvenient.

84. Except when very great regularity is required, a governor is not wanted: since, if the velocity is increased, the steam is cut off more rapidly by the eccentric, during revolution, and the waste is retained to a greater extent: both which effects tend to shorten the stroke, and, therefore, to diminish the speed. Also, the weights do not rise so perpendicularly, and, by consequence, are less powerful.

The steam cushion is effectually shut in, either by the inclined plane, or the eccentric: but not until [77] the stroke is nearly finished.

85. It is necessary to connect the extremities of the axle, steam-tight, with the steam and waste pipes. This I accomplish by a contrivance, very easy to construct and adjust: and which does not deteriorate by wear. I place a gun-metal collar on each end of the axle, so as to revolve along with it, and work steam-tight, against the face of a plate into which the steam (or waste) pipe is fastened. A packing-box is formed in one end of

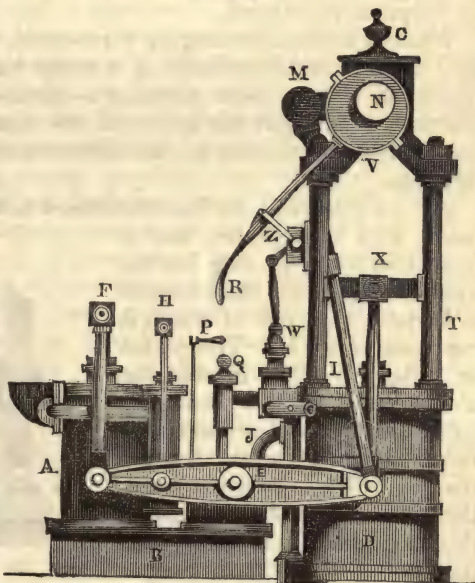
the collar, to connect it with the axle : and, when the gland [heat 41], is screwed up, not only is the ring of packing tightened, and leakage therefore prevented, but the required pressure also is supplied, and a certain degree of elasticity—which is very convenient. There is but little friction, and almost no wear, as there is an equal pressure at each side of the collar, and the rubbing surfaces are metallic. Indeed, I have found all parts of the engine to improve by wear : and it becomes if possible, more steam-tight, the longer it is in use.

86. Since it contains a crank, in principle, it has *dead points* : but it is carried past these, by its inertia :—and, when desirable, two engines [mech. 301] may be combined. It works equally well, in either direction—being reversed, and regulated, by the handle M [fig. 317]. The amount of expansion is altered, by a simple contrivance, attached to the cross-head of the valve-rod. Machinery is driven by the drum T. Many forms may be given to this engine ; and its details may be greatly varied. And, on the whole, I have no doubt that it will be found to answer extremely well : particularly when of a moderate size.

87. THE MARINE ENGINE.—Steam has long been used, on seas and rivers : and within a comparatively recent period, it has been employed, even in voyages across the Atlantic. The boiler of a marine engine requires to be more or less complicated, that a greater effect may be obtained, within a small space. Hence, even tubular boilers have been applied to marine purposes—the tubes being, however, much larger, than those of a locomotive [21]. A considerable draft is necessary, to carry off the carbonic acid which is generated by the burning fuel : and which, otherwise, would extinguish the fires. The hot-well must be so constructed, that the water in it may not be dashed about by the motion of the vessel. Two cylinders are used, to bring the crank over the dead points—a fly-wheel being inadmissible. The beam—which is made in two parts, one being at each side of the cylinder—is placed very low down, to diminish the height of the machinery ; and, as much as possible, to depress the centre of gravity. The marine engine must be capable of working in either direction. Hence, the situation of the eccentric, on the crank axle, must be alterable, so that it may be fixed in either of two positions, one exactly the reverse of the other : or it must be capable, by an easy change in the mode of connecting it with the valve, of imparting different motions to the latter ; or, finally, two eccentrics must be attached to each engine. When the engines are reversed, the vessel does not move immediately in the opposite direction nor even stop, except the speed is very trifling. The paddles are able only gradually to destroy the great momentum which has been generated.

88. The details of a marine engine admit of many modifications; but the principles on which it is most commonly constructed, are very similar, and may be understood from fig. 318. D, is one of the cylinders; E, one of the two side beams, into which the working beam [87] is divided: X, is the cross-head of the piston-rod, which moves up and down perpendicularly, on guides T, W. Connecting rods, at each side of the cylinder, unite the cross-head, with one extremity of each side beam—which is connected, also, by IM, a forked rod, with the crank M. An eccentric, keyed on the crank axle N, works the slide-valve of the cylinder, by means of the bell crank Z. F, the cross-head of the air pump, is attached, by connecting rods, to the other extremities of the side beams. H, is the cross-head, belonging to a pump which supplies the boiler; and which, also, is attached, by connecting rods, to the beams.

FIG. 318.



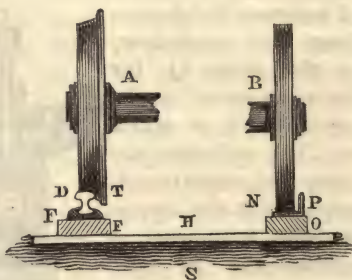
89. LOCOMOTIVE ENGINES, are those which are intended for drawing trains on railways, &c. They must be constructed, with as much regard as possible, to both lightness, and strength—which increases the cost of original construction, and of subsequent repair. Their boilers are generally cased with wood which is a bad conductor, to prevent the loss of heat in passing rapidly through the air: and [21] they are still more complicated than those of marine engines. But the danger of explosion, is greatly diminished, by the wear being confined, principally, to the tubes. Two cylinders are employed for the reasons, already given [87: and mech. 301]. Sometimes, they are placed ver-

tically, but, in most cases, horizontally, or, making an angle with the horizon. When they are fixed outside, a pin is attached to each of the driving wheels, so as to form a kind of crank, which is united with the piston-rod by a connecting rod. If they are placed between the wheels or, to prevent loss of heat by radiation, in the space through which the waste steam from the cylinders, and the heated air, &c. from the furnace is conveyed, cranks are constructed on the axle of the driving wheels [mech. 297]: and, to prevent oscillation from the inequality of the moving mass [80], at opposite sides of the wheel, they are counterpoised. The farther they are, from a line which passes through the centre of the engine, and is in the direction of its length, the greater the strain arising from the power acting, alternately, at opposite sides. Great oscillation occurs, from the motion of the piston, and other reciprocating parts, being so frequently changed.

When a locomotive engine is reversed, the driving wheels do not, like the paddle wheels of a steam vessel [87] move immediately in the opposite direction:—their adhesion to the rails prevents this. But the action of the steam on the piston gradually destroys motion in one direction, and produces it in the opposite.

90. An iron road, for locomotives, &c., is constructed, in some cases, with tram-plates, shown in section by P, fig. 319, but almost always, with rails formed in various ways, one of which is represented by D. The plates or rails, are fixed in metallic blocks, called *chairs*: and the latter are bolted down to transverse pieces of wood, termed *sleepers*. When rails are used, the wheels are, on account of the way in which they are constructed, kept in their proper position, without lateral friction—except, in curves.

FIG. 319.



91. Coke is burned in the furnace, since the production of smoke would be attended with great inconvenience. Sometimes, what is left in the retort after the manufacture of coal gas is employed; but it is found more economical, to prepare coke, intended for locomotive engines, &c., by allowing the volatile portions to go to waste, or to be consumed. If the gas were made of a quality, sufficiently good for the purposes of illumination, the coke would be deteriorated.—This will be understood better, when I describe the manufacture of coal gas. Wood is burned in various parts of Austria, and other places

where coal is scarce ; but the speed is not so great, as when coal is used. The effect produced at night, in these cases, by the volumes of flame and sparks, issuing from the chimney, is very striking.

92. The maximum speed of an engine, on a railway, depends upon the number of strokes made in a given time. As locomotives are generally constructed, a speed of one mile per minute, requires about 300 strokes of each piston. The velocity may be accurately obtained, "by multiplying the number of strokes of one engine by the perimeter of a driving wheel, and dividing the product, by the number of feet in a mile." A species of chime is produced by the steam, as it escapes from the chimney :—this will frequently, enable us to ascertain the number of strokes, if we count how often it is repeated, per minute.

93. The resistance to the escape of steam from the blast-pipe, at high velocities, is very considerable. It has been estimated, in some cases, at more than 12 lbs. per square inch : and in others, from the pressure of the steam in the cylinder being very much less than that in the boiler, at thirty or forty per cent. of the pressure on the piston. But the diminution of pressure arising from the increased space occupied by the steam, cannot [10] cause a loss of effect, except the speed is so high that the steam can do little more than follow the piston. However, it is certain that in locomotives, power must, in some way be wasted, at high velocities, to an enormous extent. For, calculating by the quantity of water evaporated per hour [63], some of them should be of about four hundred horse power : which must be totally different from what is really the case, and shows that the sources of diminution [62] are still more numerous in locomotive than in stationary engines.

94. The smaller the driving wheels, the more rapid must be the motion of the piston, to produce a given velocity : and when the speed is very high, the wear of the reciprocating parts is extremely great. If the wheels are five feet in diameter, each piston must have its motion changed about six times in a second, for thirty, and twice as often for sixty miles an hour :—and the movements of the slides, &c., must correspond. To diminish this inconvenience, the diameter of the driving wheels is often very much increased—the piston, &c., being in proportion.

95. When a railway is perfectly horizontal, 9 lbs. will draw a ton weight upon it ; and every seven feet per mile, of ascent, will add nearly 3 lbs. to the force required for traction. A rise by no means considerable, would be impracticable to a locomotive : since the wheels would revolve without communicating motion—which, indeed, often occurs, even on levels, when the rails are very wet, or very dry. The force of traction, on a level, being ascertained, it is easy to find that which is required

on a given incline.—For, the power is equal “to the weight, divided by that number of feet of the incline which corresponds with a vertical ascent of one foot.”* Thus, when there is an ascent of one foot in 249 feet, the power, required for traction, is the 249th part of the weight to be drawn: that is, about 9 lbs. per ton. Hence, an ascent of one in 249, doubles the resistance; and it would, therefore, require the same power to draw a weight one mile along such an ascent, as two miles on a level. Although inclined planes save as much force during descent, as they absorb during ascent, they are attended with the inconvenience of requiring a varying power—which it is difficult to produce, economically, by means of a steam-engine; since it cannot, like an animal, expend much energy, when much is wanted, and but little, when little is required. Contrivances have, been occasionally employed, in the application of the steam-engine to locomotion, which, by throwing wheels, of greater or less diameter into gear, render the same power more, or less, effective—the velocity being [mech. 152] proportionably lessened. Also, the diminution of atmospheric resistance, consequent on decreased speed, is found to compensate in a great degree for the increased difficulty in ascending an inclined plane: and the reverse in descending it. Moreover in ascending, the supply of water by the pumps may be stopped, or diminished: which allows the more effective production of steam.

96. Curves, on a railway, are a source of wear, and sometimes of danger. They cause the flanches of the wheels to rub with violence against the rail; and, the tangential force produced by them, is liable to overturn the carriages, or throw them off the line. A curve, of even half a mile radius, is not quite safe, particularly when it is at the bottom of a gradient—where the velocity is likely to be great.

97. The limiting angle of resistance [mech. 339], on a railway, is found to be such as that, with a descent of one, in about 270, the load would begin to descend of itself, both friction and the resistance of the air being taken into account; and the motion, thus produced, by gravity, would continue uniform. When an incline is very steep, the train is drawn up, by ropes, and a stationary engine. It is, in this way, conveyed under Liverpool; and up the great incline, at Aix-la-Chapelle, &c.

98. LOCOMOTIVE ENGINES, ON ORDINARY ROADS.—The many difficulties, which attend the application of steam to ordinary roads, have hitherto prevented—and will, most probably, continue to prevent—its employment, for that purpose. The force

* The power is to the weight, as the height is to the length [mech. 225]. Therefore, calling the height, unity, $P : W :: 1 : \text{length}$, and $P = \frac{W}{\text{length}}$.

required for traction, is vastly increased, by the absence of rails and by the ruts, &c. [mech. 216 and 218] which are perpetually to be encountered: and which create a necessity for such complicated and delicate machinery, as must be the source, not only of great expense in the original construction, but also of a very serious additional wear and tear. It has long since been found, that carriages *can* be drawn along common roads, even when they contain steep ascents;—but it remains to be discovered, how this can be done, economically. It is very injurious to a heavy engine, to drop even through the small distance which is unavoidable at the joints, in passing from one length of rail, to another. But, the fall from stones, and the descent into ruts, very commonly to be met with on ordinary roads, must be attended with the worst consequences.

99. ATMOSPHERIC RAILWAY.—The great expense, which arises from the use of locomotive engines, has caused many contrivances to be suggested, for the propulsion of carriages, &c. Among these one of the most remarkable, perhaps, is the atmospheric railway, on which an experiment has been made, for a considerable time past, between Kingstown and Dalkey:—but the expected saving has not been realized. The first project of this kind, was that of moving carriages, *within* a large cylindrical tube, by means of a piston driven forward by atmospheric pressure—the air in front of it being rarified, by an air pump, worked by a steam-engine, &c. Such a plan, however, was evidently impracticable. The contrivance was rendered feasible, by the adoption of a smaller tube, laid down between the rails of a railway: and having within it, an air-tight piston, connected with the leading carriage, by a bar passing through a longitudinal opening in the upper part of the tube—kept closed, in front of the piston, by a peculiar valve, &c.

100. PROPOSED SUBSTITUTES FOR STEAM.—Machines, extremely similar to the ordinary steam-engine, but worked by water [hyd. 134], are very much used, on the Continent. The difficulties which accompany them arise from the shocks that occur [hyd. 91], on suddenly checking the motion of water: from the, in practice, inelastic nature of that fluid [hyd. 4], and the necessity of moving the valves, by means of springs, weights, &c., independently of the motion of the piston, and after it had come to a state of rest at each end of the cylinder—the supply being then just cut off.

101. Experiments have been made, having for their object, the production of an elastic fluid, which might constitute a convenient, and economical substitute for steam. One that boils at a lower temperature than water, will produce vapour, having a given elastic force, with a smaller consumption of fuel; for the elastic force of vapour depends [heat 84] upon the distance

between the temperature, at which it is formed and the boiling point of the fluid by which it is generated. Hence, when the boiling point is lowered, the temperature, at which a vapour of any given pressure will be generated, is also lowered. Dr. Ure has found, by experiment, that alcohol, specific gravity, 813, boils at 173° : and that the pressure of its vapour, at a temperature of 264° : is equal to 161.1 inches of mercury. According to Caigniard de la Tour, sulphuret of carbon, has, at a temperature of 212° , a pressure of 4.2 atmospheres; at that of 302° , a pressure of 13 atmospheres; and at 628.25° , of 135.5 atmospheres.

102. Other fluids, also, have been tried:—but none of these experiments have been attended with practical results. The advantage arising from the low point at which alcohol, &c., vaporizes, is only seeming: for, while the vapour of water has a specific gravity of 0.6235, that of alcohol is 1.603, and that of ether 2.586. Hence though water requires for vaporization 997° , alcohol but 442° , and ether but 302° , the useful effect of the caloric with water being expressed by 10,000, with alcohol it will be only 8,776, and with ether 7,960. The lighter fluids would require a larger boiler for the same weight of them, and would besides produce a smaller amount of vapour: for a pound of water will form about 21 cubic feet of steam, but a pound of ether but 5 cubic feet.

103. Condensed air, heated air, and carbonic acid—disengaged from common limestone, and other carbonates—have been proposed as substitutes for steam; but nothing, yet suggested, seems at all likely to supersede it.

LECTURES

ON

NATURAL PHILOSOPHY.

PART II.

CHAPTER I.

INORGANIC CHEMISTRY.

Nature, History, and Division of the Science, 1.—Divisibility of Matter, 8.—The Elements, with their Equivalents, and Symbols, 13.—Chemical Language, 18.—Chemical Processes, 40.—Chemical Apparatus, 72.—Affinity, 115.—Circumstances which modify Chemical Affinity, 126.—Dyeing, 137.—The Laws of Affinity, 142.

1. NATURE, HISTORY, AND DIVISION OF THE SUBJECT.—Chemistry* is a science, which teaches us the nature of those elements, that constitute all the substances, with which we are acquainted; the mode of their combination; and the properties of the resulting compounds.

2. It is one of the sciences, which are entirely of modern creation. In the earliest times, arts were practised, and processes were employed, which, indeed, are strictly chemical; but which, nevertheless, do not necessarily suppose any acquaintance with chemical science. They were not accompanied with a collection of, and a reasoning from facts and experiments: nor did they imply any cognizance of its laws, or principles. Chemistry was alike unknown to the sages of Egypt, and to the philosophers of Greece. It even sprung originally, from delusion, and folly;—since its first and, for a long period, its only object was the production of gold and silver, and the discovery of a “universal remedy” by which every disease might be cured.

3. The earliest mention of chemistry, in any book extant, is

* Fourcroy gives no less than seven derivations of this word; but does not consider any of them as, even plausible.

to be found in the dictionary of Suidas, a Greek writer of, it is probable, the eleventh century, under the word *chemia*. He describes it to be the preparation of gold and silver.—There is some reason to believe that it was known to the Greeks, in that sense, so early as the fifth century.

4. A knowledge of chemistry—or, as it was first called, *alchemy*—passed, about the ninth century, from the Greeks to the Arabians, who began, at that period, to pay great attention to the preparation of medicines. It was introduced by the Arabians into Spain; and, finally, spread through every part of Europe, causing an infatuation which lasted, with little diminution, for many centuries, and which—notwithstanding the denunciations of the wise, and the penalties, inflicted on its votaries, by kings and princes—carried away enormous multitudes: nor did it cease, until, being gradually dissipated by the progress of knowledge, it finally disappeared in the seventeenth century.

5. The alchemists imagined that all metals are composed of the same ingredients: and that the baser differ from gold and silver, only by being contaminated with impurities, which might be removed.—They denominated the substance which was expected to produce this effect “the philosopher’s stone,” “the magistry,” &c.: and many of them believed, or affected to believe, that they had discovered, or were in possession of it. The descriptions which have come down to us, of the mode of preparing it, are, for the most part, a mere jargon, that cannot be understood: and was not, perhaps, ever intended to be so. Lives were wasted, and fortunes dissipated, in the vain attempt to obtain it: and, so great was the delusion which prevailed, that those who could not procure as much gold and silver, as would relieve their necessities, succeeded in persuading the credulous, that they were ready to impart, for a reward, the mode of obtaining them, in abundance:—and, to keep up the deception, they had recourse to numerous expedients, which their dupes were unable, or unwilling to detect.

6. Although the labours of the alchemists were never rewarded by the attainment of their objects, they were, undesignedly, greater benefactors to mankind, than if they had succeeded beyond their utmost hopes. Their researches ultimately led to the discovery of one of the noblest, and most generally useful of sciences—one that is, in some way, or another, connected with every art and manufacture, whether intended to fabricate the necessities, the comforts, or the luxuries of life. The alchemists discovered a vast number of the most important substances; and invented most of the processes and apparatus, that are still used in chemistry.

Since the middle of the seventeenth century, the progress of this science has been most rapid; but it may almost be said to

have reached its present state of perfection, within the last century.

7. Chemistry is divided into *inorganic*—or that which treats of simple bodies, with their more immediate, and less complicated compounds; and *organic*, which treats of those combinations, that belong to substances, having organs of increase, repair, and reproduction—that is, which are derived from the animal, or vegetable kingdom. Some compounds, however, such as oxalic acid, which, on account of their simplicity, are conveniently treated of in inorganic chemistry, are found among organic substances.

8. DIVISIBILITY OF MATTER.—It is usual, at the commencement of chemistry, to inquire if matter is infinitely divisible, or not. The dispute, on this point, is very ancient; but the reasoning, adduced in favour of infinite divisibility, merely shows either that the “space” occupied by matter can be divided *ad infinitum*; or that the Creator, had he so willed it, could, without any contradiction in terms, have made it divisible without limit.

9. Many arguments, on the other hand, seem to place it beyond a doubt, that matter is, in point of fact, divisible only within certain limits. Thus the doctrine of *atomic* weight* actually teaches us the “relative” weights of the atoms belonging to the various elements. For, it is found, that only a certain quantity of one element, will unite with a given quantity of another: and that, if we exceed either of these quantities, the excess will be mechanically mixed, but not chemically united with the rest.—Hence, we must conclude that, in a given quantity of any element, there are a certain number of atoms which can unite with a given quantity of another, only because the number of atoms in that other, is equal to, or is a multiple, or sub-multiple of the number of atoms of the former:—so that, if we exceed the proper weight of either substance, we add atoms, for which there are no corresponding atoms in the other. It follows from this, that we can ascertain the *equivalents* or relative weights of atoms, though far too minute to be perceived, even with the aid of the microscope. In a compound which contains an atom of each of the elements composing it—water for instance—the smallest particle will have the same proportion, by weight, of each element, as the largest possible quantity. Hence, a single particle of water will contain, by weight, eight times as much oxygen as hydrogen; and, by consequence, an atom of oxygen, will be eight times as heavy as an atom of hydrogen—provided the water really consists of but one atom of each element.

10. Dr. Wollaston lays it down as a proposition, apparently incontrovertible, that, if the gases were infinitely divisible,

* *A*, a privative particle; and *temno*, I cut. *Gr.*

they must, from their elasticity—on account of the then infinite source of repulsion, the number of repelling particles being infinite—extend through infinite space; each planet would have an atmosphere, the density of which would depend on its size; and all the atmospheres would be of the same kind.—But this, certainly, is not the case. It is true, that some of the planets might have such an atmosphere, without our being able to ascertain its existence; since that of the moon, for example, would be—from her smaller bulk—only as dense as ours, at the distance of 5,000 miles from the earth. Our inquiry must, therefore, be directed to a much larger body. This cannot, be the sun, since we are not able to say what atmospheric change would be produced by its, probably, elevated temperature. Jupiter presents no such difficulty; yet our observations on that planet do not favour the opinion that the atmosphere is infinitely diffused. For, if it had the atmosphere that in such supposition it would have, its fourth satellite, when behind its centre, would, on account of refraction [opt. 9], be visible at each side of it:—which does not occur.

However, the argument derived from this source is not, it must be admitted, very conclusive.

11. The doctrine of the non-divisibility of matter, beyond a certain limit, was taught by Epicurus, and Lucretius. Newton remarks that water, composed of broken, could not be the same, as that which consists of entire particles.

12. But, though matter is not infinitely divisible, it is capable of being divided to an amazing extent. Platinum wire has been drawn, by Wollaston, for astronomical purposes, so fine, that it may be easily proved not to have exceeded the 18,000th part of an inch, in diameter.—To obtain it, he surrounded the platinum with silver; then drew the compound wire; and afterwards dissolved away the silver, with nitric acid. A single grain of ammoniacal hyposulphite of silver, will render 32,000 grains of water intensely sweet. A grain of iodide of potassium, dissolved in 480,000 grains of water, and mixed with a little starch, will, on adding some chlorine water, render the entire fluid blue. The black spot on a soap-bubble, before it bursts, is only the 2,500,000th part of an inch in thickness. Gold, on silver wire, may be visible to the naked eye, although only the 864,000,000th part of an inch; and, with the microscope, if only the 432,000,000,000th part. Professor Ehrenberg has shown that there are, in fluids, such vast numbers of minute animals, that a single drop may contain 500,000,000—a number more than half as great, as that of all the human beings on the earth; and yet, each of these creatures is furnished with organs of motion, &c. If the globules in the blood of minute animals, bear the same proportion to the size of their bodies, as the

globules of our blood bear to ours, how inconceivably small must they be. For 890,000 red globules of the human blood are required to cover a superficial inch : and* 25,000,000 when deprived of their colouring matter.

13. THE ELEMENTS; WITH THEIR EQUIVALENTS, AND SYMBOLS.—The ancients are supposed, by many, to have considered earth, air, fire, and water, as the elementary substances of which all bodies are composed. But the most enlightened of them seem to have looked upon these, merely as examples of the four different states, which modern science teaches us really belong to matter—the solid, the fluid, the gaseous, and the ethereal. For, Plato, in *Timeus*, says, “Let us therefore speculate, concerning the nature and properties of fire and water, air and earth. This is the more arduous, because it is necessary to call into question, concerning each and all of them, whether they should be denominated liquid rather than ethereal, or aerial rather than solid; or why any thing should have one of these appellations, rather than all. For, in the first place, that which we now call water, being congealed, becomes as stone or earth; but being melted and diffused, it becomes gas or air; and this inflamed, becomes fire; and fire extinct, becomes again congregated into air: and air, collected and condensed, forms mist and cloud; and these again, more compressed, form water; and from the water, earth, and stones are reproduced. And thus they, in an endless circuit, produce each other. Since, then, these now appear to be the same, who will assert that one of them is of the one kind, rather than of the other. It is most safe, therefore, to speak thus:—that the thing we see is not absolute liquid, but something in the liquid state; that air is not necessarily a gas, but something in the gaseous state; not as being a particular thing of this or that specific nature, but that it is in such and such condition. Let us then distribute the four modifications of matter into fire, earth, water, and air; and to earth let us assign an entical form, for it is the most immovable of all; to water that which is less movable than the other three; to fire the most easily movable form; and to air that which is intermediate.”

14. However various the bodies which constitute the globe, the elements to which they may ultimately be reduced, are extremely few. These have been variously divided.—By Thompson, into *supporters* of combustion, and *non-supporters*. But, when, for instance, water is produced by the combustion of hydrogen, the hydrogen may, with equal truth, be said to burn the oxygen, as to be burned by it. And the same body, sulphur for example, may be at one time a supporter, and a combustible at another. Berzelius divides them into *electro-*

* Phil. Trans.

negative, and *electro-positive*—according to that pole of the battery [gal. 62] to which they go. But, as I have remarked, the same substance may be *electro-positive*, with one body, and *electro-negative*, with another. For convenience, we shall divide them into metals, supporters of combustion, and combustibles—indicated by *met. sup.* and *comb.* They are, at present, sixty-two in number. With their symbols—generally derived from the first one, or two, letters of their names—and their equivalents or atomic weights [9], so far as the latter have yet been ascertained, they are, according to the best authorities, as follows:—

Name.	Symbol.	Equivalent.
Aluminum,	Al. . <i>Met.</i>	13.63
Antimony,	Sb. . <i>Met.</i>	129.20
Arsenic,	As. . <i>Met.</i>	74.92
Barium,	Ba. . <i>Met.</i>	68.39
Bismuth,	Bi. . <i>Met.</i>	70.95
Boron,	B. . <i>Comb.</i>	10.90
Bromine,	Br. . <i>Sup.</i>	79.97
Cadmium,	Cd. . <i>Met.</i>	55.74
Calcium,	Ca. . <i>Met.</i>	20.00
Carbon,	C. . <i>Comb.</i>	6.00
Cerium,	Ce. . <i>Met.</i>	46.05
Chlorine,	Cl. . <i>Sup.</i>	35.47
Chromium,	Cr. . <i>Met.</i>	27.99
Cobalt,	Co. . <i>Met.</i>	29.48
Columbium,	Ta. . <i>Met.</i>	184.90
Copper,	Cu. . <i>Met.</i>	31.68
Didimium,	D. . <i>Met.</i>	—
Erbium,	Er. . <i>Met.</i>	—
Fluorine,	F. . <i>Sup.</i>	18.86
Glucinum,	G. . <i>Met.</i>	26.54
Gold,	Au. . <i>Met.</i>	98.33
Hydrogen,	H. . <i>Comb.</i>	1.00
Ilmenium,	Il. . <i>Met.</i>	—
Iodine,	I. . <i>Sup.</i>	126.85
Iridium,	Ir. . <i>Met.</i>	98.84
Iron,	Fe. . <i>Met.</i>	28.00
Lanthanum,	La. . <i>Met.</i>	48.00
Lead,	Pb. . <i>Met.</i>	103.73
Lithium,	L. . <i>Met.</i>	6.55
Magnesium,	Mg. . <i>Met.</i>	12.62
Manganese,	Mn. . <i>Met.</i>	27.56
Mercury,	Hg. . <i>Met.</i>	100.07
Molybdenum,	Mb. . <i>Met.</i>	47.96
Nickel,	Ni. . <i>Met.</i>	29.53
Niobium,	Nb. . <i>Met.</i>	—
Nitrogen,	N. . <i>Comb.</i>	14.02
Osmium,	Os. . <i>Met.</i>	99.72
Oxygen,	O. . <i>Sup.</i>	8.00

Name.	Symbol.	Equivalent.
Palladium, . . . .	. Pd. . <i>Met.</i>	. 53·00
Pelopium, . . . .	. Pe. . <i>Met.</i>	. —
Phosphorus, . . . .	. P. . <i>Comb.</i>	. 31·32
Platinum, . . . .	. Pl. . <i>Met.</i>	. 98·84
Potassium, . . . .	. K. . <i>Met.</i>	. 39·12
Rhodium, . . . .	. R. . <i>Met.</i>	. 52·20
Ruthenium, . . . .	. Ru. . <i>Met.</i>	. 52·10
Selenium, . . . .	. Se. . <i>Comb.</i>	. 39·63
Silicon, . . . .	. Si. . <i>Comb.</i>	. 21·35
Silver, . . . .	. Ag. . <i>Met.</i>	. 107·92
Sodium, . . . .	. Na. . <i>Met.</i>	. 22·97
Strontium, . . . .	. Sr. . <i>Met.</i>	. 43·65
Sulphur, . . . .	. S. . <i>Comb.</i>	. 16·00
Tellurium, . . . .	. Te. . <i>Met.</i>	. 64·25
Terbium, . . . .	. Tb. . <i>Met.</i>	. —
Thorium, . . . .	. Th. . <i>Met.</i>	. 59·83
Tin, . . . .	. Sn. . <i>Met.</i>	. 58·82
Titanium, . . . .	. Ti. . <i>Met.</i>	. 24·33
Tungsten, . . . .	. W. . <i>Met.</i>	. 94·80
Uranium, . . . .	. U. . <i>Met.</i>	. 60·00
Vanadium, . . . .	. V. . <i>Met.</i>	. 68·66
Yttrium, . . . .	. Y. . <i>Met.</i>	. 32·25
Zinc, . . . .	. Zn. . <i>Met.</i>	. 32·53
Zirconium, . . . .	. Zr. . <i>Met.</i>	. 33·67

15. When the elements of substances are expressed by symbols, the number of atoms of each element, is indicated by small digits, placed under the symbol. Thus NO_5 , which denotes nitric acid, shows that it consists of the two elements, nitrogen and oxygen: and that there are one atom of nitrogen, and five atoms of oxygen. Some chemists would express nitric acid, by NO^5 ; others, by $\text{N}+5\text{O}$. When compound atoms are to be indicated, their number is expressed, by digits prefixed to their symbols. Thus HO means a single atom of water: but 2HO means two atoms of water. A compound, formed by two or more substances, is—without supposing any particular combination of the elements, after they have been united—very conveniently expressed, by connecting their symbols, with the sign $+$. Thus, SO_3+KO means sulphate of potash, containing an atom of sulphuric acid (SO_3), and an atom of potash (KO). We are not to confound chemical with mathematical symbols.

16. When an element enters into combination, in the proportion of one and a half to one atom of another, *sesqui** is prefixed to the name of the compound. Thus *sesqui-oxide* of iron, contains the oxygen and iron, in the proportion of one and a half atom of the former, to one atom of the latter.

17. The atomic weight or chemical equivalent of a compound atom, is the sum of the equivalents of the atoms which consti-

* *Sesqui*, one and a half. *Lat.*

tute it. Thus, the atomic weight of sulphuric acid (SO_3) is $40 = 16 (\text{S}) + 3 \times 8 (= \text{O}_3)$.

18. CHEMICAL LANGUAGE.—Modern science has greatly simplified chemistry, by reducing its laws to a few great principles: and by arranging the compounds it affords, in a few great classes.

Compounds are *primary*, consisting of two elements—as water (HO), sulphuric acid (SO_3) &c.: *secondary*, consisting of two primary—as sulphate of soda ($\text{SO}_3 + \text{NaO}$): *ternary*, consisting of two secondary—as ordinary alum in the dry state $[(\text{SO}_3 + \text{KO}) + (3\text{SO}_3 + \text{Al}_2\text{O}_3)]$: *quaternary*—as the same alum in the crystalline form $[(\text{SO}_3 + \text{KO}) + (3\text{SO}_3 + \text{Al}_2\text{O}_3)] + 24 \text{ Aq}$: &c. Primary are sometimes called *binary* compounds: but the latter term is more correctly used to express a substance containing a single atom of one element combined with a single atom of another—as water (HO). Hence all binary are primary compounds: but not *vice versa*. As none but true binary compounds are decomposed, *primarily*, by the galvanic current [gal. 63], such decompositions may help us to discover what are, and what are not binary compounds.

19. *Acids* are substances which redden litmus paper,* and form salts with oxides:—the former test is, however, sometimes wanting, as, for instance, in silicic acid. The *radical* of an acid, is the element united with the acidifying principle. *Ox-acids* derive their acidity from oxygen; and are divided into those which have a simple radical—as sulphuric acid; and those which have a compound radical. The latter are subdivided, into those whose radical consists of carbon and hydrogen—as acetic acid; those whose radical consists of carbon and azote—as cyanic acid; and those whose radical consists of carbon, hydrogen, and azote—as uric acid.

20. When two acids are formed from the same element, the name of that which has the smaller quantity of oxygen, ends in “ous”—as sulphurous acid; and of that which has the larger quantity, in “ic”—as sulphuric acid. When there are several acids of the same element, there are various modes of distinguishing them. Thus, some have the word *hypo*† prefixed to their names—as *hypo*-sulphuric acid, which has more oxygen than sulphurous, but less than sulphuric acid; *hypo*-sulphurous, which has less oxygen than sulphurous acid. When an acid contains more oxygen than that which ends in “ic,” it has *hyper*‡ prefixed to its name—as *hyper*-chloric acid, which is called, for brevity, *per*-chloric acid, and has more oxygen than chloric.

* Paper which has been tinted blue, with the colouring matter of litmus, a species of *Lichen*:—it is one of those called “test papers.”

† *Hupo*, under. Gr.

‡ *Hyper*, over. Gr.

21. An *hydracid* derives its acidity from hydrogen. Many chemists now suppose that all acids are, in reality, hydracids: some being a combination atom for atom—as hydrochloric acid (HCl); and others a combination of hydrogen with a compound atom—as oil of vitriol, which, if an oxacid, is $\text{SO}_3 + \text{HO}$ but, if an hydracid, $\text{SO}_4 + \text{H}$. Hydracids, unlike some of the oxacids, never require water for their existence—that fluid merely dissolves them: and there is never more than one hydracid of the same radical.

When the acidifying principle is sulphur, *sulph* is prefixed—as *sulph*-arsenious acid.

A vegetable acid is briefly represented by the first letter of its name, with a line above. Thus acetic acid, by $\overline{\text{A}}$.

22. *Oxides* are substances, formed by the union of elements with oxygen—the latter not being in such quantity as to produce acidity. The *base* of an oxide, is the element combined with the oxygen. Thus, lead is the base of oxide of lead. If the oxide restores the colour of litmus paper, reddened by an acid [19], it belongs to the class of substances, termed *alkalies*: in which case, it will also change the yellow colour of turmeric paper to brown, and will turn an infusion of red cabbage green.

23. If there are several oxides, formed by the same element combining with oxygen in different proportions, that which has the least oxygen is termed the *protoxide*,* that which has the next greater quantity, the *deutoxide*,† that which has the next greater, the *tritoxide*,‡ &c., and that which has the most, the *hyper* or *per-oxide* [20].

24. If a substance requires a larger quantity of oxygen, before it is capable of uniting with an acid, it is called a *sub-oxide*.

25. *Salts* are combinations of ox-acids with oxides: of sulph-acids with sulphurets: or, of the radical of the acid with the base of the oxide. The first are termed *oxy-salts*, &c., the second *sulphur-salts*, and the last *Haloid salts*.§ The *base* of a salt, is the oxide which is combined with its acid. Thus potash is the base of sulphate of potash.

26. Sometimes water acts the part of a base—forming a salt with an acid. And some chemists even suppose that many acids, ordinarily considered as mere solutions, are actually united with water, so as to form a salt. Thus they consider oil of vitriol—a combination of one atom sulphuric acid, and one atom of water—as sulphate of water. When the latter constitutes the base of a salt it, occasionally, forms with the acid a

* *Protos*, first. *Gr.* † *Deuteros*, second. *Gr.* ‡ *Tritos*, third. *Gr.*

§ From *hals*, the sea. *Gr.*—Because sea-salt, consisting of chlorine (the radical of hydrochloric acid), and sodium (the base of soda), is a type of that class of salts.

crystalline compound. The basic water, very frequently, cannot be separated, but with great difficulty; and, often—unless it is replaced by some other substance—not without the acid being decomposed. This occurs with the nitric, acetic, and oxalic acids: which, no doubt, are salts of water.

27. Before water was discovered to constitute a base, it was found hard to understand the three phosphoric acids: which, if the water combined with them is not taken into account, contain precisely the same elements, although they have very different properties. But the difficulty disappears, if they are considered a *mono-basic*,* *bi-basic*,† and *tri-basic*‡ acids:—the first, being an atom of phosphoric acid and an atom of water; the second, an atom of phosphoric acid and two atoms of water; and the third, an atom of phosphoric acid and three atoms of water. Some of the basic water may be replaced, the rest remaining in combination. Thus, tribasic phosphate of soda, is an atom of phosphoric acid, two atoms of soda, and one atom of water; its crystals contain twenty-four atoms of water; and it throws down a white precipitate, if added to a solution of nitrate of silver. But, when this salt is exposed to a red heat, and then crystallized, its crystals are of a different form, and contain only ten atoms of water; and, if added a solution of nitrate of silver, it will give a yellow precipitate. It has become, by the action of the heat, *bibasic* phosphate, termed *pyro*§-phosphate of soda, and contains an atom of phosphoric acid, united with two atoms of soda.

28. If the name of the acid of a salt terminates in “ous” [20], that of the salt terminates in “ite.” Thus, sulphite of lime, consists of sulphurous acid and lime. But if the acid ends in “ic” the salt ends in “ate.” Thus, sulphate of lime, contains sulphuric acid and lime.

29. The salts of *protoxides* [23] are called *proto-salts*, &c.: those of the *per-oxides* *hyper* or *per-salts*.

30. If the salt contains fewer atoms of the base, than of the acid, the prefixes *bi*,|| *tri*,¶ &c. are used. Thus, bi-tartrate of potash contains two atoms of tartaric acid, and one of potash. But, if the salt contains more atoms of the base than the acid, the prefixes are derived from the Greek. Thus, *di*-phosphate of magnesia contains one atom of phosphoric acid, and two atoms of magnesia. A salt is *basic*, when it contains more than one atom of base, provided some of the latter, has replaced “water of crystallization:”—basic nitrate of copper, consists of one atom of nitric acid, three atoms oxide of copper, and one atom of water.

31. The power of a base to saturate an acid, depends on the

* *Monos*, alone. Gr.

† *Bis*, twice. Lat.

‡ *Tris*, thrice. Gr.

§ *Pur*, fire. Gr.

|| *Bis*, twice. Lat.

¶ *Tris*, thrice. Lat.

number of atoms of oxygen it contains. Thus, protoxide of iron, having one atom of iron, and one atom of oxygen, is saturated with one atom of sulphuric acid; but peroxide of iron, which has two atoms of iron, and three atoms of oxygen, requires three atoms of sulphuric acid, for saturation.

32. When a salt has neither acid nor alkaline properties, it is termed a *neutral* salt; if it reddens litmus paper, it is said to be an *acid* salt; if it restores reddened litmus paper, it is an *alkaline* salt.

33. From their resemblance to oxides, the compounds of elements with chlorine, iodine, bromine, and fluorine, are termed *chlorides*, *iodides*, &c.

Sometimes oxides combine with chlorides, iodides, &c., producing basic haloid salts—termed *oxy-chlorides*, *oxy-iodides*, &c. Thus, the oxy-chloride of copper, formed on the sheathing of ships, by the action of the sea water.

34. If a non-metallic element combines with another, with a metal, or with a metallic oxide, the name of the resulting compounds ends in “uret.” Thus, sulphuret of iron, which consists of an atom of sulphur, and an atom of iron; *bi*-sulphuret of iron, which consists of two atoms of sulphur, and one atom of iron; *sesqui*-sulphuret of iron, which consists of iron and sulphur, in the proportion of one atom of the former, to one and a half of the latter. From their resemblance to sulphurets, compounds of the elements with cyanogen, selenium, &c., are termed *cyanurets*, *seleniurets*, &c.

Oxides sometimes combine with sulphurets, forming oxy-sulphurets. Thus, oxy-sulphuret of antimony. Sulphurets combine with chlorides:—thus, chloro-sulphuret of mercury.

35. If water unites with a substance, the result is called a *hydrate*.* Thus, the hydrate of an acid. The water may even assume the solid form:—as, in hydrate of lime. In such cases, heat—often very intense—is evolved. Hence, bottles have been burst, by the sudden generation of steam, arising from oil of vitriol being poured into them, after they had been rinsed with water, and not dried. Ships, laden with lime, have been burned at sea, on account of the heat produced by sea water leaking in, and slaking the lime. I have already noticed [heat 79], that the specific heat of a body, depends on the space it occupies.—When the water combines with the oil of vitriol, condensation occurs: and, by consequence, a diminution of specific heat. Also, when it combines with the lime, being changed from the fluid to the solid form, its specific heat is diminished.

36. The combination of different quantities of water, with the same substance, occasionally produces marked differences,

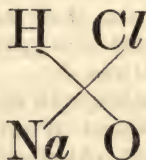
* *Hudōr*, water. *Gr*.

in the resulting compounds. Thus, seleniate of zinc unites with three different portions of that fluid, and assumes three different forms—according as, when crystallizing, it is hot, cold, or lukewarm. Water, united with potash, seems to act the part of a feeble acid:—we have seen [26] that it often acts as a base.

37. It may be proved that water combines *chemically* with bodies, by many examples. Thus, crystallized sulphate of copper ($\text{SO}_3 + \text{CuO} + 5\text{HO}$), exposed to a temperature of 150° , loses four atoms of the water; but the remainder is not driven off, even at 300° . The constitution of this salt is, therefore, $\text{SO}_3 + \text{CuO} + \text{HO}$. This last atom of water may, however, be expelled by sulphate of potash, “a double salt” [$(\text{SO}_3 + \text{CuO}) + (\text{SO}_3 + \text{KO})$] being formed.

38. Water of crystallization is represented by *Aq.** Thus, crystallized protochloride of tin is $\text{SnCl} + 3\text{Aq}$: anhydrous,† or without water, it is SnCl . The three atoms of water are those required for crystallization.

39. Chemical changes, which occur, on mixing substances, are represented by very simple methods. Thus, $\text{HCl} + \text{NaO} = \text{NaCl} + \text{HO}$, means that, if hydrochloric acid (HCl), and soda (NaO) are mixed (in solution), the results will be chloride of sodium (NaCl), and water (HO). The same would be more fully expressed as follows:—



And, whenever a process is given, in the former way, the student will do well, for his own improvement, to illustrate it, in the latter, also.

The abbreviations of chemistry, whether those of language, or those which express substances, &c., are extremely useful: and should be both well understood, and carefully remembered.

40. CHEMICAL PROCESSES are very numerous, and varied:—it will be proper to explain, here, the most usual and important, that no misapprehension may hereafter arise. The object of a chemical process may be, either *analysis*,‡ or *synthesis*,§ or a combination of both. Analysis resolves a body into its elements: synthesis forms it, from them.

41. *Solution*.—A body is said to be dissolved, when, being placed in a liquid, it loses the solid form, and ceases to be

* *Aqua*, water. *Lat.*

† *A*, a privative particle; and *Hudōr*, water. *Gr.*

‡ *Ana*, severally; and *luo*, I set free. *Gr.*

§ *Sūn*, together; and *tithemi*, I place. *Gr.*

visible. If water is the solvent, the result is termed an "aqueous solution," or simply a "solution:"—and when no other solvent is mentioned, it is supposed to be water. If the solvent is alcohol, or ether, it is an "alcoholic," or an "etherial solution"—or a "tincture." A solution is said to be "saturated," when it is incapable of dissolving any more of the solid. Sometimes the latter, on being dissolved, colours the fluid, or changes its colour.

42. Solution is often employed to separate bodies. Thus, if there is a mixture, containing substances which are soluble in a given fluid, and others which are not, so; those which are soluble will be dissolved out by, and may be removed along with it; while the insoluble, will be left behind. Sometimes a mixture of two fluids is employed. Common salt, for example, may be separated from sulphate of lime, by a mixture containing one part alcohol, and two or three of water—in which the sulphate of lime is quite insoluble, though it is sparingly soluble in water alone.

43. *Maceration*, &c.—When the substance is dissolved out, without heat, the process is called "maceration." *Lixiviation* is a combination of maceration and filtration—a process to be explained presently. If the substance to be acted upon, is left for some time in moderately warm water, it is *digestion*; but if boiled with the fluid, it is called *decoction*. If, while the fluid is boiling, it is poured on a substance and left to cool, the process is said to be *infusion*.

44. Sometimes the substance is changed, during solution. Thus, oxide of iron, dissolved in hydrochloric acid, becomes chloride of iron. Sometimes, even when the solvent is an acid, the substance is dissolved unchanged. Thus hydrochloric acid merely dissolves the oxalate or phosphate of lime: and may be separated from it, by the addition of a sufficient quantity of ammonia.

45. *Precipitation*.—When a body, in solution, is rendered visible, by being made insoluble, it is termed a *precipitate*: and is said to have been "precipitated," or "thrown down." This, in some instances, arises from a change in the nature of the solvent. Thus, when water is added to a solution of resin in alcohol, the resin separates, as a powder; for though strong alcohol will, dilute alcohol will not dissolve it. Sometimes it arises, from a change in the nature of the substance dissolved. Thus, if sulphuric acid is added to a solution of chloride of calcium in water, the chloride of calcium is changed into sulphate of lime, which, being insoluble, is precipitated.

46. The precipitate does not always sink to the bottom of the fluid; sometimes it remains mixed with it, or even floats. It occasionally assumes an appearance, not unlike that of a jelly—and is then said to be a "gelatinous precipitate."

47. Too much of the “re-agent,” as the substance intended to show the presence of another is termed, must not be added:—in some instances, the precipitate is *re-dissolved by the excess*. On the other hand, there must be enough of it, or the nature of the result may be affected:—sulphuretted hydrogen, in small quantity, gives, with a solution of peroxide of mercury, a white, but in excess, a black precipitate.

48. *Decantation*.—The precipitate may sometimes be separated from the fluid, after having been allowed to settle for a while, by “decantation.” That is, by gently pouring off the liquor—which may be guided by a glass rod, as represented, fig. 320. When the precipitate is such as would be easily disturbed, a syphon [pneum. 53] may be used.

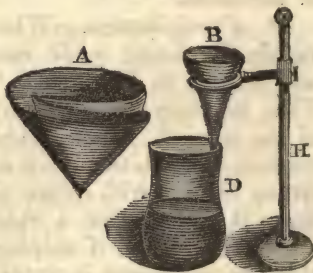
FIG. 320.



49. *Filtration*.—Sometimes, it is necessary to separate the precipitate, by means of a “filter”—which retains all the solid matter, and allows the fluid to pass through.

Filters are either *single*, or *double*; and are formed of a cheap and peculiar kind of paper, containing no size. The paper is to be doubled twice, after being cut in the form of a square—the folds being at right angles; and that corner which presents four single leaves, is to be pared, so that, when the filter is opened—as represented by A, fig. 321, the edge of the opening will form a circle. It is to be placed—thus opened—in a glass, or porcelain funnel B. The latter may be fluted, or ribbed, that the fluid may escape more easily, between it and the paper. The liquid, containing the precipitate will, on being poured into the filter, trickle down into jar D—represented of that form, which has been found most convenient, for such purposes. The filter should always be previously wetted, with distilled water:—without this precaution, some precipitates would pass through, at first.

FIG. 321.

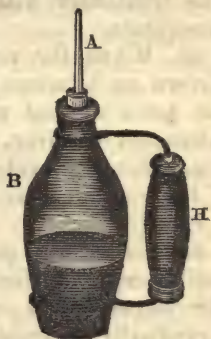


50. A *double filter* is made, by squaring, folding, &c., two pieces of paper, at the same time, instead of one: separating

them, when made : balancing them, in a pair of delicate scales : and paring the heavier, until both are of exactly the same weight. Each of them is then to be opened, as if it alone were to be employed ; and they are to be laid, one within the other, in such a way, as that the single side of one shall be next the triple side of the other.

51. When all the fluid has passed through the filter, the precipitate must be carefully washed, by projecting upon it, distilled water, &c., according to circumstances. For this pur-

FIG. 322.



pose the washing bottle of Berzelius, fig. 322, will be found to answer extremely well—since it enables us to throw the fluid strongly, against the substance to be washed. It consists of a glass tube A, drawn out fine at one end, and inserted into the cork of the bottle B, in which the distilled water, &c., has been placed. When B, having been gently heated on a stove, &c., is inverted—being held by the handle H—the temperature of the air contained in the upper part will be raised, by passing through the fluid. Consequently, it will expand, and, pressing on the surface of the fluid, will force it out in a continued stream, which may be directed wherever it is required. Blowing into the bottle, and at the same time inverting it, will produce a similar effect, by condensing air over the surface of the fluid :—but carbonic acid, from the lungs, might injure a delicate experiment : besides, most precipitates are washed more easily, by hot, than by cold liquids.

52. *Weighing a precipitate.*—When the precipitate has been well washed, which may be known by examination of the fluid passing through, the filters are to be gently folded up in some of the filtering paper : then, to be placed on a porous stone, or in an oven, and exposed to a gentle heat : and, afterwards, left for a while in the air—to re-absorb the hygrometric moisture they contained, when they were weighed previously to being used. They are, then, to be gently separated, and again weighed :—the difference of their weights, will be that of the precipitate, contained in one of them. Sometimes, it will be necessary to take out a portion of the precipitate, to weigh it, expose it to heat in a platinum, &c., crucible, and then to ascertain how much weight it has lost : from which we may calculate, by the rule of proportion, how much the whole of the precipitate would have lost, had it been possible to separate it from the filter, and dry it—or otherwise act upon it by heat, in the same way.

53. When the weight of a precipitate is to be ascertained, with but one filter, the latter, before being used, should be dried to the same extent as it will be necessary to dry the precipitate, which it is to contain : and, its weight being deducted from the weight of both it and the precipitate, the remainder will be the weight of the precipitate.

54. *Ignition of a precipitate.*—If the precipitate is to be ignited in the filter, one of exactly the same weight must be ignited previously ; and the ashes being weighed, their weight must be deducted from that of the ignited filter and precipitate. The remainder will, of course, be the weight of the ignited precipitate.

55. When the precipitate is to be merely dried, it may be thrown on bibulous paper : or it may be gently heated. If it has been washed with water, it may be placed under the exhausted receiver, along with some strong sulphuric acid, or some fused chloride of calcium—either of which, on account of their affinity for water, will absorb the vapour, as fast as it rises.

56. Sometimes, particularly when the fluid is corrosive, filtration may be effected, by placing pounded glass in a funnel. The larger lumps are to be put underneath : then others, of a gradually diminishing size—fine powder being uppermost. Sulphuric acid, &c., can, in this way, be freed from the various impurities, which it may contain in the form of a sediment.

57. In some instances, it is necessary, during filtration, to exclude atmospheric air as much as possible. In such a case, the apparatus represented, fig. 323, may be employed. It consists of a vessel A, the upper part of which is connected, by means of the tube D, with the upper part of the vessel B. The aperture in the lower extremity of A is closed by linen, &c., placed in the neck. According as B fills, by the fluid passing through the linen, &c., the air within it ascends through D, and takes the place of what has descended from A.

FIG. 323.



58. *Distillation, &c.*—When the fluid, driven off by heat in the form of vapour, is to be preserved, the process is termed “distillation.” The different temperatures, at which different fluids boil, afford us a means, in many instances, of separating them by the application of a “bath” [heat 106]. For it enables us to regulate the temperature, so as not to exceed that, required by the fluid, which is to be removed by distillation from others with which it may be mixed.

59. *Sublimation*.—If the vapour, obtained by distillation, is condensed in the solid form, the body is said to be “sublimed.”

60. *Destructive distillation*.—When, in obtaining gaseous or vaporous products, an organic body has its constitution entirely broken up—new compounds being formed by its elements, it is said to undergo “destructive distillation.”

61. *Fusion*.—If a solid body is changed by heat into a liquid, the process is called “fusion.”—When crystals melt in their water of crystallization, it is termed “aqueous fusion;” and the resulting liquid is, in reality, a *hot* solution.

62. *Crystallization*.—Sometimes a body is precipitated or sublimed, &c., in the crystalline form. In other cases it is necessary to evaporate the fluid, until that which remains is no longer able to retain the whole solid matter in solution:—some of it will then be thrown down in the form of crystals. Common salt may, in this way, be obtained from brine.

63. When more of the solid is held in solution by hot, than by cold fluid, if the solution is concentrated by evaporation, and allowed to cool, crystals will be formed. And, if these are removed, a fresh “crop” of them will be obtained, by again concentrating and cooling.

64. Crystals may, sometimes, be produced, also, by sublimation [59]. And, occasionally, the same body may be crystallized, either by solution, or sublimation: but, in such cases, the crystals which result from the two processes, are rarely of the same form, and are often entirely different:—such bodies are termed *dimorphous*.* The more slowly crystals are formed, the more perfect they are. Sometimes what is at first without a crystalline form, may gradually assume it. Thus, melted sugar is, when cooled, a hard transparent mass; but after some months it is opaque, and white—having become crystallized. In the same way, iron is found, in machines which are kept in rapid motion, to become crystalline, and lose its tenacity to a dangerous extent. This happens, after some time, with the axles of locomotives: and is a reason for great caution, with regard to tubular and suspension bridges, &c. Levers, &c., of the toughest iron, which are subjected to a considerable number of slight blows, invariably break off, after a short time: and the crystalline structure extends, in all or most instances, to but a short distance, from the fracture. The same substance may, in the same circumstances, produce crystals of different kinds. Hence, when crystals are left long in solution, they should be turned: or the growth may take place on some sides, more than others.

65. All crystalline forms are reducible to six systems—

* *Dis*, twice; and *morphê*, a shape. *Gr*.

First—The *octohedral* or *regular* system, having three *axes* of equal lengths, and at right angles to each other. Axes are lines passing through the centre of the crystal: and the different parts are symmetrically grouped around them.

Second—The *rhombohedral* system, which has three axes of equal length, in the same plane, and making, with each other, an angle of 60° ; and a fourth unequal axis, at right angles to that plane.

Third—The *square prismatic* system, which has three axes at right angles; but only two of them, equal.

Fourth—The *right prismatic* system, which has three axes at right angles; but no two of them equal.

Fifth—The *oblique prismatic* system, which has two axes making an acute angle with each other; and a third, at right angles to both.

Sixth—The *doubly oblique prismatic* system, which has all the axes of unequal lengths, and making acute angles with each other.

66. The various “secondary” crystalline forms may be considered as produced from these six “primary,” by having their new layers deposited unequally, at different sides.—The most frequent change arises from the replacement of a solid angle, or an edge, by a plane. Minerals, having a *regular structure*, are capable of *cleavage*: that is, they may be split into parts, so that the detached surfaces will be smooth. When they are cleavable in two or more directions, they may often be made to assume forms which are regular, and very different from their original figure.

If a body, which separates from a fluid, &c., is not in the crystalline form, it is said to be *amorphous*.*

67. If a substance absorbs moisture, so as to become liquid, it is said to be *deliquescent*. If, on the contrary, it loses water, so as to pass from the crystalline to the amorphous state, it is said to be *efflorescent*.†

68. When a body is pulverized, by being rubbed, it is said to be *trituated*.‡

69. A substance is *deflagrated*, by being exposed to a high heat with some other—nitre for example—which easily parts with its oxygen.

70. A body is *incinerated*§ when the coals, remaining after it has been burned, are reduced to ashes, by perfect and

* *A*, a privative particle; and *morphē* shape. *Gr.*

† From *flores*, flowers, *Lat.*; because in the act of becoming pulverulent, they first present on their surface small needles, or a powder, which—from some fancied resemblance—the older chemists termed “flowers.”

‡ *Trito*, I rub. *Lat.*

§ *Cinis*, a cinder. *Lat.*

continued exposure to the air, while they are at an elevated temperature.

71. *Cementation* consists in surrounding a solid with some other body; and exposing the whole mass in a close vessel, to a heat high, but not sufficiently so to cause fusion.—Green bottle glass is changed, by cementation with sand, &c., into porcelain.

72. **CHEMICAL APPARATUS.**—Chemists, in their experiments and researches, use a great variety of apparatus—a portion of which will be conveniently described here. What is required for exceedingly interesting, and important illustrations, &c., is neither complicated, nor expensive.

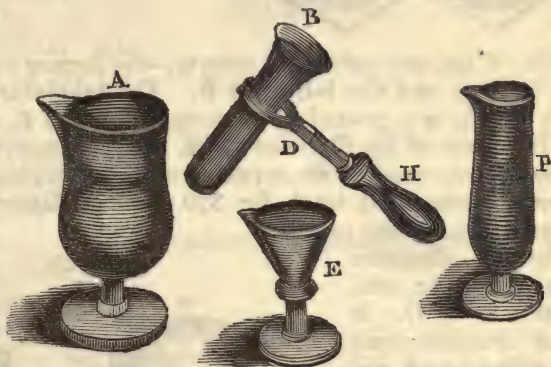
The following—of which some are more useful than others—will be found quite sufficient, until a considerable progress has been made.—

73. Glass rods. Tubes, both of common, and of Berlin glass—which bears a high temperature.

74. Test glasses, of various forms, represented by A, B, E, and P, fig.

FIG. 324.

324. B may be held over a lamp, &c., by means of the handle H, to which are attached slips of brass tightened by a loop, at D—so as to suit tubes of different dimensions.



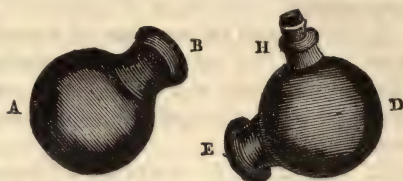
75. Bottles of various sizes: some of green, others of white glass; some with wide, others with narrow necks; some with corks, others with ground glass stoppers—and a few, with *hoods* over the stoppers, for holding ether, and other very volatile fluids. Matrasses—like what is represented, fig. 325. I may remark, here, that bottles, and other vessels, through which the air cannot pass freely, are to be dried by heating them, and then sucking out the damp air through a tube—the process being repeated, until drops of moisture, are no longer condensed on the interior, by cooling.

FIG. 325.



76. Glass receivers, of various shapes :—among others, globular, like A and D, fig. 326. The latter is tubulated at H, and has a cork, or a ground glass stopper.

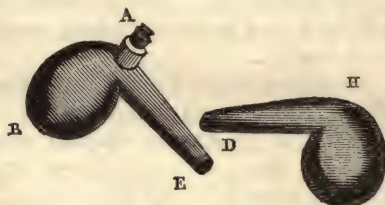
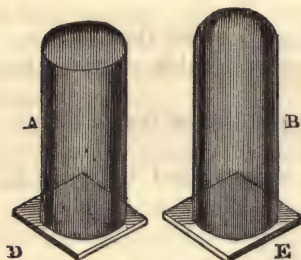
FIG. 326.



77. Cylindrical jars, like A and B, fig. 327, with ground edges—so as to rest air-tight, on ground glass plates D, and E.

FIG. 327.

FIG. 328.



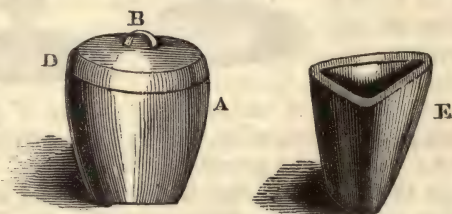
78. Plain, and tubulated retorts—the former represented by H, fig. 328, and the latter, by B. The tubulature is at A, and has a cork, or a ground glass stopper: D, and E, are the beaks.

79. Some of the Florence flasks, used for importing sweet oil.

80. Wedgewood ware capsules, and evaporating basins: the former represented, by A, fig. 320: and the latter, by F. Also, if possible, a silver capsule.

81. A platinum crucible A, fig. 329, with a cover D. A lead crucible: one of silver: and another, of black lead. Hessian crucibles, like E. A platinum spoon, and some platinum foil.

FIG. 329.



82. One of the iron bottles used for importing mercury.—It should be fitted with a ground perforated stopper, to which is attached a short tube of copper, terminated by one of block tin. The flexibility of the latter, will allow it to be bent, with great facility.

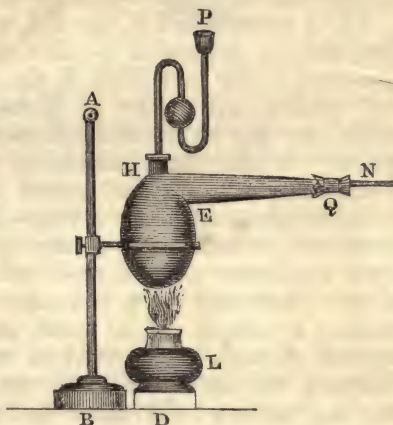
83. One or two small charcoal furnaces.

84. An argand lamp, and copper chimney. A spirit lamp, with hood.

85. Funnels of glass, and porcelain—some plain, and others ribbed [49].

86. A safety tube P, fig. 330.—If the air, within the retort E, when connected with a receiver, &c., becomes of an undue pressure, the small quantity of fluid, which is in the safety tube, being forced up into the funnel at P, the air will bubble through it, and escape. If, on the contrary, a vacuum happens to be formed, the fluid being driven into the bulb which is blown on the middle of the safety tube, the atmospheric air will bubble through, and enter. In ordinary circumstances, nothing will pass through the safety tube; and fluid may, at any time, be poured, by means of it, into the retort.

FIG. 330.



87. A sucking tube, AD, fig. 331, will be found very convenient, for removing most of the liquid over a precipitate—so as to facilitate the filtration: and, if it is used properly, the precipitate will not be in the least disturbed. D. being introduced gently into the fluid, the mouth is to be applied, at A: and the fluid is to be sucked up, until the bulb H is nearly full. The tongue being then pressed against A, the instrument may be lifted out, and the fluid transferred to another vessel. If the precipitate begins to be at all disturbed, the process must be stopped at once.

FIG. 331.



88. A pipette, or dropping tube, RN, fig. 332, may be used in taking up, and transferring small quantities of fluid. For this purpose, it should be immersed to a depth, which depends on the quantity required; and, the thumb being placed on R, it R

FIG. 332.

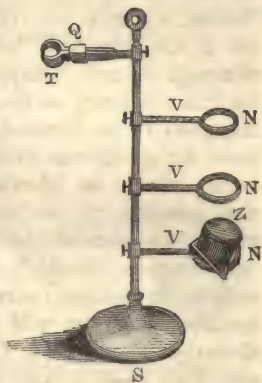
89. Syphons [pneum. 53]. A washing bottle [51].
PART II

90. A brown-ware cask and porcelain cock—for distilled water.

91. Pestles and mortars of Wedgewood ware, of agate, and of steel. The steel mortar is cylindrical, with a movable bottom; and the pestle fits it pretty accurately, that the substance, to be pulverized, may not be thrown about.

92. A retort-stand S, fig. 333, containing movable rings NN, &c., and an apparatus T—like what is attached to the test glass B, fig. 324—for holding the necks of flasks, &c., while they rest on one of the rings underneath. A platinum crucible is represented as placed on wire formed into a triangle, and laid upon a ring—which, otherwise, would be too large for it. This apparatus may be rendered more simple—and still very convenient—by making a vertical rod, of wood, pass up tightly, through corks, fixed in sockets fastened to the wires V V, &c. No binding screws will then be necessary, to keep the rings in any required position.

FIG. 333.



93. Two sets of scales and weights:—one for coarse, and the other for delicate purposes.

94. Some bladders. Some sheets, and elastic tubes of caoutchouc. The latter may be made, by drawing some sheet caoutchouc tightly over a piece of glass rod, or tube: then cutting off the parts that project with a *clean* scissors, and bringing together the severed edges—which will adhere firmly: and, if the process is properly managed, the joint will be very strong.

95. A spatula or elastic knife, with a blade of nearly uniform thickness, and blunt edges, fig. 334.

FIG. 334.



96. Rings formed of strong wire, and well covered with strips of cloth, wound tightly round them, until they are from half an inch to an inch or more in thickness—according to their size. They are used as stands for globular vessels, flasks, capsules, &c.

97. Some iron, and copper wire. Some files: and a soldering iron.

98. *A Blow-pipe* is indispensable, in the laboratory.—It consists of a tapering tube

FIG. 335.

DA, fig. 335, having at one end, a large, and at the other, an extremely small and well-formed circular aperture. The sphere, in the centre may be unscrewed,



in the middle:—it contains a small piece of sponge, to intercept any moisture, which might pass from the mouth, when the instrument, is blown through, at D. The object, to be operated upon, is placed in a hollow, made in a piece of well-burned charcoal—which, being a bad conductor of heat, may [heat 11], without inconvenience, be held in the hand, during the experiment. If charcoal is unsuitable to the process, a small platinum spoon may be employed, instead. Many other forms have been given to this instrument.

99. It is difficult to describe how the blow-pipe is to be used. The method, however, will be acquired, after a little practice. It consists, in using the mouth as a reservoir for the air, which is to be forced through the blow-pipe, by compressing the cheeks—the lungs being, at each respiration, filled through the nose. A blast may, in this way, be continued, without the least flickering—which would often be highly inconvenient—or any fatigue to the operator, for a very considerable time.

100. Different parts of the flame of a lamp, &c., produce very different effects. It is found to consist of three distinct portions—a dark nucleus in the centre, a luminous part covering the nucleus, and a kind of mantle surrounding the entire. The dark nucleus contains the gases, which are formed from the tallow, oil, &c., and are still unconsumed, for want of oxygen.—They may be conveyed out of the flame, by a slender tube of glass, and burned at its extremity. In the luminous part they are, to a certain extent, in a state of combustion. Hence that part of the flame has a tendency to deoxidize bodies placed in it, by taking oxygen from them; and is, therefore, called the “deoxidizing” or “reducing flame.” The outer coat is the hottest portion:—oxygen is there in excess, and bodies placed in it have a tendency to combine rapidly with that substance; it is, therefore, called the “oxidizing” flame. The stream of air, from a blow-pipe, rushing in, mixes with the gases in the interior of the flame, and causes combustion *inside*: the hottest place, being at a certain point H, which is marked by a bluish light, and is a little beyond the apex of the inner nucleus. The combustion, which, in the ordinary flame, is spread over the surface, is in that of the blow-pipe, concentrated to a small space.

101. To produce the oxidizing flame E, fig. 336, the jet of the blow-pipe is introduced almost the tenth of an inch within the flame, and immediately above the wick—a gentle uniform blast being maintained. The flame then assumes the form represented by EP.

FIG. 336.



102. When the “reducing” flame is required, the orifice in the jet of the blow-pipe must be smaller: and it must not enter the flame, but must be kept just on its edge; the wick should be of moderate length, cut very even and smooth; the blast must be tolerably strong, and must be thrown higher over the wick, than when the oxidating flame is to be produced. In this case, a roaring noise is made, and the appearance of the flame is represented by R. The oxidizing may be considered as the ordinary flame turned, as it were, inside out: but the reducing, as the ordinary flame, turned down.

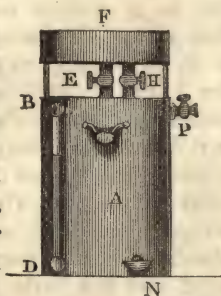
103. Sometimes the blow-pipe is connected with a bladder, or an oiled silk bag, containing oxygen; which, being pressed out, by the hand, &c., produces a very strong flame. It is, very often, connected with reservoirs containing, respectively, oxygen and hydrogen, in the proportions, which constitute water;—a very intense heat is then obtained.

104. The table blow-pipe consists of a double bellows, worked by the foot;—it supplies, without any trouble, a strong, and continuous blast.

A candle, a spirit lamp, an argand lamp, &c., may be used with the blow-pipe: but tallow, and a large flat wick, is most effective.

105. *The Gas-holder*, fig. 337, consists of a cylindrical vessel A, formed of tinned sheet iron—or, which is much better, of sheet copper tinned inside—and of a shallow cylindrical tray F, of equal diameter, supported immediately over, and at some little distance from it. A tolerably large tube, having a union joint above the tray and a cock E between it and the vessel, passes down, water-tight, from the centre of F, through the top of A, and reaches almost to the bottom of the latter. Another tube, fixed near the former, is like it in every respect, except that it has no union joint above, and enters A, without passing down for any distance through it. The cock P, is fixed outside, and very close to the top of A. The glass tube BD communicates, by means of short

FIG. 337.

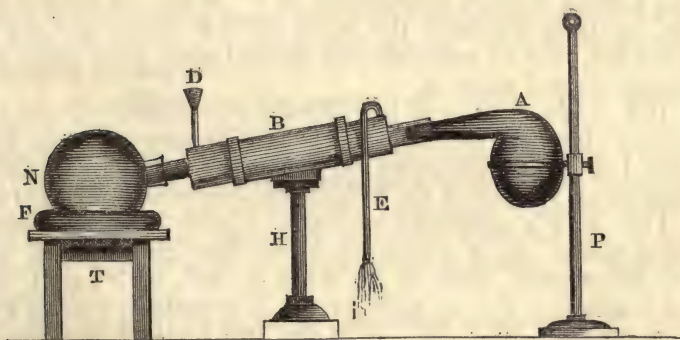


bent metallic tubes, with the highest and lowest parts of the vessel. There is an aperture at N, capable of being closed perfectly, by a plug which screws into it.

106. When gas is to be introduced into A, the cocks which are in the pipes forming a connexion between it and the tray, are to be opened, the cock P is to be closed, and the plug at N screwed in: water is then to be poured into the tray, until the vessel is filled. After this, the cocks being closed, the plug at N may be removed, and the beak of the retort, or whatever else is to convey the gas into A, may be introduced, instead of it. Water will not escape at N, being kept in by atmospheric pressure [pneum. 44], until it is displaced by the ascending gas: and when it has all flowed out, the plug may be screwed in, again. If gas is to be taken from A, the cock E is to be opened: and, water being poured into the tray, it will descend, and force out the gas through the cock P, as soon as the latter is turned. P may be connected to a tube, &c. The quantity of gas in A, can always be seen, by the glass tube BD, the water in which stands at the same level, as what is inside A.

107. *The Distilling Apparatus*, fig. 338, is used for the distillation of water, acids, &c. It consists of a heavy stand H, on which is placed—so as to be capable of making different angles with the horizon—a metallic tube B, of mode-

FIG. 338.



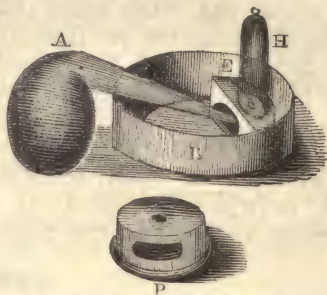
ately large diameter, and closed, at each end with a piece of cork, &c. A glass tube passes water-tight through the corks, and projects a few inches beyond them. A funnel D is placed, at one end of B; and a syphon E, at the other. The space, between the metallic and glass tubes is to be filled, by pouring water in at D, until it begins to flow out at E. The lower end of the glass tube may be placed in the neck of a globular receiver N, resting in a ring [96] F, placed on the stand T; and the upper may be connected with a retort A, in which is placed

the water, &c., to be distilled, and which rests on the stand P. The vapour is prevented from escaping, between the end of the glass tube and the beak of the retort, by a piece of moistened bladder tied over them. As the vapour passes through B, it is condensed, and drops in the fluid state into N. The water in B is gradually heated; but the hotter portion, being the lighter [heat 17], ascends towards the higher end. As long as there is any cold water in the apparatus, it will be found at the lowest part: so that the vapour must pass through it, and be condensed. If cold water is poured in at D, it will drive the hot water up before it, and out through the syphon E.

108. *Pneumatic trough*.—Fig. 339, represents a simple form of pneumatic apparatus. It

FIG. 339.

consists of a porcelain or other vessel B, containing water. A jar H, having ground edges [77], is filled with water; then covered with the ground glass plate: and—being inverted—is placed, with its mouth under water, immediately above the aperture in the shelf E. A very convenient arrangement may be made, by means of a dish, or any ordinary vessel of the kind, and a stand or shelf, represented by P. As the gas ascends into the jar H, it displaces the water—which descends: and H, when full, may be removed—the ground glass plate being previously slipped under it.

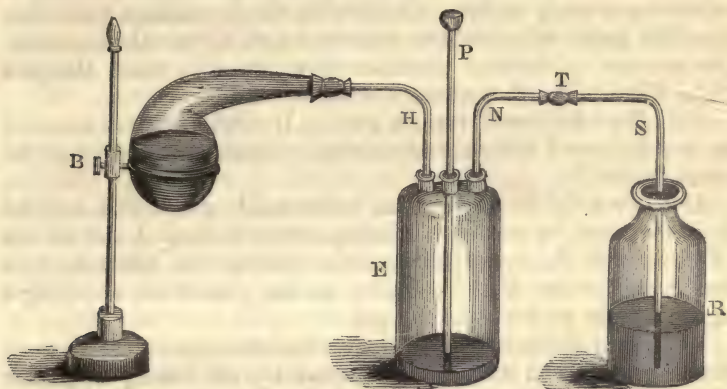


109. Some gases must be collected over mercury, instead of water:—but the mercurial pneumatic apparatus differs from what I have just described, only in being, generally speaking, smaller, on account of the weight, and dearness of the mercury.

110. *Wolf's apparatus* consists of a bottle E, fig. 340, having three necks. It is connected, by the bent glass tube H, with the retort which rests on the stand B; and, by N and S, with the bottle R. The air-tight joint at T, is made by placing a bit of caoutchouc tube [94] over the two ends of the angular tubes that are to be united; and tying a thread round each end of it. P, serves as a kind of safety-tube [86]. The joint, at T, being, to some extent, flexible, prevents the apparatus from being injured by a slight derangement. Corks are fitted carefully into the necks of E, and are rendered perfectly air-tight by *luting*: which may consist, according to circumstances, of plaster of Paris, or putty. The latter is termed *fat lute*, and is rendered very secure, if a piece of wet bladder is tied over it. Wax, which is little affected by acids, may sometimes be conveniently employed as a lute.

Sometimes two or more bottles, like E, are used in the same experiment.

FIG. 340.



111. The application of baths, as a means of regulating temperature, has been already noticed [heat 106]. They are very frequently employed in chemistry, for producing a suitable and steady heat. Besides the *water bath*, called by the older chemists "*balneum maris*," or "*balneum mariæ*"—and which is exemplified in the better kinds of glue pot—a *sand bath*, also, is used. It consists of sand, placed in a vessel, under which is the furnace, lamp, &c :—the retort, &c., to be heated, is placed in the sand. When coal gas can be had, a sand bath is seldom necessary.

112. In addition to the method of cutting glass, already noticed [heat 20], circular pieces, like watch glasses, and extremely useful, may be cut from broken retorts, &c., by placing upon them metallic rings well heated, and then suddenly cooling the glass by sudden immersion in mercury, &c.

113. Drills, files, &c., will cut glass, with facility, if they are well rubbed with a solution of camphor in spirits of turpentine.

114. The end of a tube, &c., may be strengthened, so as not to burst when a cork is inserted in it, and its sharp edges may be rounded, by keeping it, for some time, in a state of fusion, with the flame of a blow-pipe.

115. AFFINITY.—We have seen [mech. 12] that there are various kinds of attraction. That which is termed *chemical affinity*, differs from all others, on account of "changing the nature of the substances, upon which it acts."—When very strong, it is accompanied by heat; and in many cases by light, also.

116. The following are some examples of the effects produced by affinity—

Two gases will form a solid.—If a glass cylindrical jar is held over strong hydrochloric acid, some of the latter, in the form of gas, will ascend into it; and if a similar jar is held over water of ammonia, some of the latter will pass up in the same way—neither gas being visible. On placing the jars mouth to mouth, the two gases will combine together and form sal-ammoniac, the minute crystalline particles of which will cause the jars to be filled with what seems a white smoke.

117. Two fluids will form a solid.—If sulphuric acid is added to a solution of chloride of calcium, sulphate of lime will be precipitated.

118. Two fluids will form an inflammable gas.—This may be demonstrated, by mixing a small quantity of alcohol and excess of oil of vitriol, in a capsule; then heating the mixture, in a flask: and, when all the common air has passed off, applying a lighted taper to the escaping gas.

119. Two fluids will give rise to spontaneous combustion.—Nitric acid, mixed with a small quantity of strong sulphuric acid, will set fire to oil of turpentine, when thrown upon it. Since the combination is so violent, that some of the mixture will be scattered about, the acids should, for security, be poured from a small vessel, which has been tied to the extremity of a rod.—The sulphuric acid strengthens the nitric acid, by combining with a portion of its water. It also takes up any of that fluid which may be associated with the oil of turpentine.

120. Solids will give rise to spontaneous combustion.—Loaf sugar trituated, and mixed with a small quantity of chlorate of potash, in powder, will inflame, if touched with the end of a glass rod which has been dipped in oil of vitriol.

121. A solid and fluid will produce a spontaneously inflammable gas.—This may be proved, by dropping dry phosphate of lime into water; or throwing ether on a small quantity of chlorate of potash, which has been moistened with oil of vitriol.

122. Two solids will cause explosion.—Thus, a *very* minute quantity of sulphur and chlorate of potash, rubbed in a mortar: or a *very* small bit of phosphorus, rolled up with a crystal of chlorate of potash, in paper, and struck on an anvil, with a hammer. If there is no open side left in the paper: or, if the open side is turned towards the experimenter, he will sometimes be injured, by the burning phosphorus which may be scattered about. To prevent such an inconvenience, it is well to leave one side of the paper unfolded, and to turn the opening in such a direction, as that, whatever may be driven through it can cause no injury. Also, the hand in which the hammer is grasped, should be wrapped in a cloth.

123. A solid and cold fluid, will cause explosion and flame.—

Thus, a minute quantity of chlorate of potash, mixed with some phosphorus, or sulphur, and thrown into a little oil of vitriol.

124. Combustion may be effected under water.—Phosphorus will burn under warm water, if oxygen is thrown on it by means of a tube which leads from a bladder, or oiled silk bag, a gentle pressure being applied.

125. Affinity changes, or destroys colour.—Solutions of sugar of lead, and of iodide of potassium, are clear, and colourless; but, when mixed, they are found to contain a beautiful yellow powder. Solutions of iodide of potassium, and of corrosive sublimate, also are clear, and without colour; but when they are mixed, a beautiful red powder is, at once, precipitated.—Should either of the fluids be added in excess, the red solid will be re-dissolved [47], and the solution will be colourless. If paper, rendered blue with litmus, is held over the fumes of an acid, it will become red; if it is then held over the fumes of ammonia, its blue colour will be restored; and if, lastly, it is held over water containing chlorine in solution, its colour will be permanently destroyed.

126. CIRCUMSTANCES WHICH MODIFY CHEMICAL AFFINITY.—Chemical affinity is modified, by a variety of circumstances. Some elements have a tendency to unite, only in the *nascent* * state; that is, at the very moment of their being separated, by decomposition, from others with which they had been combined.

127. *Quantity of matter* will affect chemical affinity.—Thus, if common salt is added to water, it will be dissolved less and less rapidly, until at length the solution is saturated [41].

128. *Heat* will modify chemical affinity.—Thus hydrogen will restore heated oxide of iron to the metallic state, water being formed; but water will be decomposed by heated iron, oxide of iron being formed and hydrogen being disengaged. In the former case, the hydrogen, and in the latter, the iron, had the greater affinity for oxygen. If three substances are mixed together, two of them being capable of forming a compound more volatile than the third, that compound will be produced, and will be driven off by the heat. Thus a mixture of lime and sal-ammoniac (hydrochloric acid and ammonia, or chlorine and ammonium), when heated, gives off ammonia. This principle may sometimes explain, what occurs when either of two substances may be decomposed, according to the circumstances.—Sal-ammoniac, on applying heat, is decomposed by dry carbonate of lime, chloride of calcium and carbonate of ammonia being formed; although if a solution of chloride of calcium is mixed with a solution of carbonate of ammonia,

* *Nascor*, I am born. *Lat.*

carbonate of lime, and sal-ammoniac, will be the result. Heat favours affinity, when a diminution of cohesive power is advantageous; but, the contrary, when it gives rise to the gaseous form, either by separating the elements, or keeping them disunited—on account of the greater distance it places between them. Explosive mixtures are no exception to this law; since, probably, the very expansion caused by heat brings some of the particles within the sphere of each other's attraction.

129. *Partition of elements.*—Affinities are sometimes modified by circumstances, which might not be supposed likely to produce any effect:—thus the more difficult solubility of one of the compounds present in a solution. If, for example, spring water, containing hydrochloric acid, sulphuric acid, &c., soda, lime, &c., is evaporated, the sulphate of lime present, being very insoluble, will first be precipitated: then, although the sulphuric acid united with the soda is held in combination by strong affinities, a new division of it will take place, and more sulphate of lime will be formed—which, also, will be precipitated; and this process may go on, until all the sulphuric acid present is thrown down in combination with lime, notwithstanding the stronger affinity of the sulphuric acid for the soda, than for the lime. In such cases, if the substance produced is very insoluble, the entire acid will be removed with such rapidity, that the effect will seem to be instantaneous—which occurs, when sulphate of barytes is formed by mixing nitrate of barytes and sulphate of soda. This principle may often modify the effect, when *double* decomposition occurs—that is, when two substances mutually decompose each other. It does not arise from greater force of affinity, since acetic acid will decompose carbonate of potash; although carbonic acid decomposes a solution of acetate of potash in alcohol.—The potash being “divided” among the acids, carbonate of potash, which is insoluble in alcohol, separates as fast as it is formed. This division of each acid, among all the bases, and of each base among all the acids, though it does not always happen, occurs, undoubtedly, in many cases: and even when precipitation does not take place.—Thus, if sulphocyanic acid is mixed with sulphate of iron, the solution will become of a blood red colour: showing that the stronger has given some of the iron to the weaker acid.

130. *Elasticity* modifies affinity, by causing repulsion, and thus driving off a portion of the elements. Hence, [128] carbonate of ammonia will be given off from a mixture of carbonate of lime and sal-ammoniac, heated in the “dry state.” The volatility, due to increased temperature, produces, on account of the division of the elements among each other [129] the

same kind of effect as results from insolubility, when a precipitate is formed. This explains the expulsion of carbonic acid, by silex, in certain processes to be noticed hereafter; also the hydrochloric acid driven off, when common salt is thrown on heated pottery; and the separation of water, at a high temperature, from substances for which it has a very strong affinity.

131. *Light*, as we have seen [opt. 119], affects affinity; and the results depend on the nature of the rays.—If chlorine is exposed to ordinary light, it will afterwards, in the *dark*, unite with hydrogen: except it has been subsequently exposed to red rays.

132. *Elective affinity*.—A substance may have an affinity for a number of others, but may choose one of them in preference to the rest. This is called “elective affinity.” Thus, if mercury is added to nitrate of silver, it will be dissolved, and the silver will be precipitated in the metallic state. Copper will separate the mercury from the nitric acid, taking its place in the solution; lead will throw down the copper from the acid; and zinc will throw down the lead.

133. The order of affinities is different, with different substances. Thus, with sulphuric acid, it is—

Baryta,
Strontia,
Potash,
Soda,

Lime,
Ammonia,
Magnesia,
Oxide of silver.

But with hydrochloric acid—

Oxide of silver,
Potash,
Soda,
Barytes,

Strontia,
Lime,
Magnesia.

Each acid will leave any substance, to combine with one that is higher on the list to which it belongs. Hence the strong base, with one acid, may be the weak, with another.

134. A substance unable, by itself, to decompose a compound, may, in combination, have that power.—Sulphate of barytes is not affected by potash, but it is partially decomposed, by carbonate of potash. The affinity of the carbonic acid for the barytes, assists that of the sulphuric acid, for the potash.

135. Substances may decompose each other, without forming new compounds.—Thus, oxide of silver decomposes peroxide of hydrogen; and is, at the same time, itself changed into metallic silver and oxygen. Substances may even affect chemical affinity, without, themselves, acting chemically.—A small quantity of dilute sulphuric acid, boiled with starch, changes it

into crystallizable grape sugar, without being itself in the least altered. Peroxide of hydrogen is violently decomposed, by finely divided platinum. Such effects arise from a principle termed *catalysis*.*

136. Chemical substances may, by a species of infection, communicate new properties to others.—Platinum, in any state of division, is insoluble in nitric acid; but a compound of platinum and silver dissolves in it. Copper, boiled with dilute sulphuric acid, does not decompose water; an alloy of copper, zinc, and nickel does—the copper being dissolved. It would seem that electrical action [gal. 22], ought to have preserved the platinum, or the copper; but it appears that the chemical action, is the more powerful.

137. DYEING.—A knowledge of chemical affinity is the foundation of the art of dyeing: since it enables the dyer to produce the various colours, and to render their union with the cloth permanent.

138. The substance to be dyed, whether woollen, linen, cotton, or silk, must be previously cleaned. When the cloth and the dye have little or no affinity, it is necessary to employ a *mordant*,† which, having an attraction for each, causes them to combine together. Calico printers used the solid excrements of the cow, to brighten and fasten their colours; but phosphate of soda, is now employed, instead of it;—the efficacy of the excrements being due to the phosphates they contain.

139. The most important mordants are alumina, the oxides of tin, and iron, the tannin contained in nut-galls—which has a powerful affinity for cloth, and for various dyes, &c. Alumina is applied, in the form of alum, or of acetate of alumina—which answers better for cotton, and linen. When cloth is stamped with, or steeped in acetate of alumina, and then heated, the acetic acid flies off, and the alumina, which remains behind, combines with the cloth, and subsequently with the colour also.

140. Sometimes, the whole cloth is soaked in the mordant, and the colour is then printed on, with blocks, &c.: after which, the mordant is washed out—except in the spots, at which the colour has been applied, where it remains fixed. Sometimes, the cloth is steeped in the colouring matter, and the mordant is printed on, the colour being afterwards removed by washing—except where it has been rendered permanent by the mordant. When a white pattern is to be formed, the mordant is often removed, by the blocks containing the designs; and the cloth is then steeped in the colouring matter, and washed. Or, finally, the cloth is dyed of a uniform colour,

* *Kata*, severally; and *luo*, I set free. *Gr.*

† *Mordeo*, I bite. *Lat.*

and then stamped, in patterns, with substances which destroy, or change it.

141. Different colours may, in some cases, be obtained from the same dye, by the use of different mordants.—Cochineal, with alum, will form a crimson; but, with iron, a black. Indigo requires no mordant; its solvent is sulphuric acid, and its colour is due to oxygen.—It is of a greenish yellow, and is soluble in lime water, if deprived of its oxygen. It may be deoxidized, by the application of some substance having a greater affinity for oxygen—protoxide of iron, for example; but it will reabsorb oxygen from the atmosphere, and again become blue.

142. THE LAWS OF AFFINITY.—It has already been remarked that the elements do not combine in indefinite proportions [9]. This fact is the great foundation of the "atomic theory," which has contributed so much to the advancement of chemistry; and which supposes that the ultimate elements of bodies have a definite size, shape, and weight. What these are can be only conjectured. A very probable notion of their shape may, indeed, sometimes be formed: for, however small we break a body which crystallizes—carbonate of lime in the form of Iceland spar, for instance—it still retains the same form. Consequently, if we could render it so minute in quantity, as that it would consist of but one compound atom, it is natural to suppose the shape of that atom would be the same as the shape of the largest mass.—Chalk, in the most minute powder to which it can be reduced, is found, under a powerful microscope, to be an assemblage of crystals, each as perfect as the finest specimen of calcareous spar.

143. The first law of chemical affinity is, that "the proportion in which substances unite, chemically, is invariable." They combine atom for atom. Thus, if an atom of one element along with an atom of another forms a certain compound, an atom of one cannot combine with half an atom of the other—for there is no such thing: nor with two atoms, since its affinity is satisfied with but one.

144. The second law is, that "bodies, whether they consist of simple or compound elements, contain these elements in proportions that are some multiples of their atomic weights." That is, if an element enters into any combination, however complicated, with one or more others, their weights will be proportional to their chemical equivalents: or, as the chemical equivalent of one is to some multiple of the chemical equivalent of another. Thus, if a given compound consists of hydrogen and oxygen, the atomic weight of which are, respectively, one and eight, for every one ounce, or grain of hydrogen there will be found 8, 16, 24, &c., ounces, or grains of oxygen: or

for every 8 ounces, or 8 grains of oxygen, there will be found 1, 2, or 3, &c., ounces, or grains of hydrogen. This law can be proved experimentally.—If one equivalent of tartaric acid, and one of potash, each in solution, are mixed together, a soluble salt will be formed: but if two equivalents of tartaric acid and one of potash are the proportions used, bitartrate of potash, an insoluble salt will be the result.

145. There are some apparent exceptions to the “law of multiples,” as this is called.—Thus there are two oxides of iron, the protoxide the constitution of which is FeO , and the peroxide the constitution of which is Fe_2O_3 . The former contains an atom of oxygen, for every atom of iron, and the latter, an atom and a half of oxygen, for every atom of iron:—but an atom and a half is evidently not a multiple of unity, by an integer. There are two methods of explaining this apparent difficulty. We may consider that what is ordinarily taken as the equivalent of one atom of oxygen, is in reality the equivalent of two:—the protoxide would then be, FeO_2 , and the peroxide FeO_3 . Or, as frequently occurs with the oxides of iron and manganese, we may suppose that the peroxide is a combination of two oxides, one being FeO , the other FeO_2 , and both together Fe_2O_3 . Red lead is an example of a compound, consisting of a peroxide and a protoxide.

146. The third law is that, “when one body unites with two or more different quantities of another, these quantities are to each other in a very simple ratio.” This is well exemplified, as we shall see, by the compounds of nitrogen and oxygen—in which the oxygen is to the nitrogen, as 1 to 1, as 2 to 1, as 3 to 1, as 4 to 1, and as 5 to 1.

147. Lastly, “gaseous substances unite in volumes.” That is, “if two gases combine, it will be in proportions that are equal to, or multiples of some common volume.” And it should be remarked, that, “the volume of the resulting compound, bears a simple ratio to the volumes of its elements.” Thus, two volumes of hydrogen combine with one of oxygen, to form one volume of the vapour of water.

148. *Isomeric* bodies* are those which consist of the same elements, in the same proportions; but differ in their properties. This difference may arise, in some cases, from their being differently grouped. Thus, sulphate of potash ($\text{SO}_3 + \text{KO}$) may be considered as $\text{SO}_3 + \text{K}$, $\text{SO}_3 + \text{KO}$, $\text{SO}_2 + \text{KO}_2$, $\text{SO} + \text{KO}_3$, or $\text{S} + \text{KO}_4$, &c.: and these different arrangements of the same atoms, were they to exist, might well be supposed to produce very different qualities. The three phosphoric acids have been given as examples of isomerism; but we have seen [27] that,

* *Isos*, equal; and *meros*, a part. *Gr.*

their water being taken into account, they are differently constituted.

149. The difference may arise in other cases, as, in certain compounds of carbon and hydrogen, from the amount of condensation which occurs at the moment of production. Thus olefiant gas, (C_2H_2) contains two volumes of carbon vapour and two volumes of hydrogen, which condense into one volume; and etherine, (C_4H_4), four volumes of carbon vapour and four volumes of hydrogen, which condense into one volume. Oil of citron (C_5H_4) has the same constitution as oil of turpentine; but, when the former is combined with hydrochloric acid, it becomes $C_{10}H_8$: while the latter, in the same circumstances, becomes $C_{20}H_{16}$. Again, alcohol ($C_4H_6O_2$) and methylic ether (C_2H_3O) each contain the same elements, in the same proportion; but the former can be resolved into ether and water: while the latter cannot.

150. *Isomorphous* bodies* are those which have the same crystalline shape. We may infer [142] that their ultimate atoms also are, probably, isomorphous. But, it is not universally true, that isomorphism arises from this cause. Thus arsenic acid (AsO_5) and phosphoric acid (PO_5) are said to be isomorphous, because each forms three classes of salt, which are, respectively, isomorphous. The arsenic acid itself, crystallizes in the *rhombohedral* [65]: and the phosphoric, in the *regular* system.

151. Bodies may be isomorphous, without having their angles exactly equal, which rarely occurs. Indeed the very same body does not always crystallize, in precisely the same manner:—unequal heating, or cooling, may alter an angle.

152. Isomorphous bodies can be substituted for each other, without affecting the external character of the compound:—the atoms of the different elements will be the same in number, the crystals will remain of the same shape, &c.

153. Isomorphous bodies easily crystallize together; and are separated with difficulty.

154. Certain bodies assume, in different circumstances, a difference of physical constitution. This is called, by Berzelius, the *allotropic†* state. Thus, sulphur is solid, at one temperature, fluid at a higher, viscous at a yet higher, and liquid at a still higher. Iron, as we shall find, is rendered, by nitric acid of a certain strength, unalterable by oxidizing agents.

* *Isos*, equal; and *morphē*, a form. *Gr.*

† *Allos*, another; and *tropos*, a character. *Gr.*

CHAPTER II.

The elements of water. Oxygen, 155.—Combustion, 160.—Respiration, 171.—Hydrogen, 180.—Water, 186.—Peroxide of hydrogen, 198.—Components of atmospheric air. Nitrogen, 200.—Atmospheric air, 204.—Nitrous oxide, 215.—Nitric oxide, 218.—Hyponitrous acid, 220.—Nitrous acid, 225.—Nitric acid, 229.—Ammonia, 244.—Terechloride of azote, 257.—Carbon, 259.—Carbonic oxide, 263.—Carbonic acid, 266.—Olefiant gas, 272.—Light carburetted hydrogen, 274.—Gases for illumination. Coal gas, 276.—Oil gas, 287.

155. THE ELEMENTS OF WATER—OXYGEN: *—*ymb. O.: equiv.*
 8. This substance was discovered, by Priestly, in 1774. It has been called by different names—"dephlogisticated air," "eminently respirable air," "pure air," "vital air," "oxygenous principle," and, finally, by Lavoisier, "oxygen," a term which is very objectionable, because founded on the supposition, that it is the only cause of acidity, an hypothesis long since proved to be at variance with the fact.

156. Oxygen is a most abundant, and highly important element. It forms, by weight, eight-ninths of water: and by measure, nearly a fifth of the atmosphere: and is a constituent of stones, earths, &c.:—neither animals nor vegetables could exist, without it. There are various modes of obtaining it. Peroxide of manganese (MnO_2), when heated, gives off one-third of its oxygen; and, when acted upon by sulphuric acid (SO_3), it yields twice as much—but the temperature required, is likely to break the retort. If the peroxide is merely heated, a combination of oxide and sesquioxide remains, after the oxygen has been liberated.—This compound is analogous to black magnetic oxide of iron; formed in a smith's forge, and also when iron is burned in oxygen. If the manganese is acted upon by oil of vitriol, five atoms of the peroxide become, by a gentle heat, one atom of permanganic acid (Mn_2O_7), and three atoms of protoxide ($3MnO$). Exposed to a higher temperature, the atom of permanganic acid becomes two atoms manganic acid ($2MnO_3$), and one atom of oxygen. The heat being still further increased, the manganic acid is changed into protoxide: which unites with the sulphuric acid of the oil of vitriol, forming sulphate of the protoxide of manganese.

157. When oxygen is derived from manganese, it is more or less impure; but this is not the case when it is obtained by

* *Oxūs*, sharp; and *gennao*, I produce. *Gr.*

heating chlorate of potash ($\text{ClO}_3 + \text{KO}$). Two atoms of this salt are changed into one atom chloride of potassium (KCl), and one, perchlorate of potash ($\text{ClO}_7 + \text{KO}$)—oxygen being evolved: and, when the temperature rises still higher, the perchlorate becomes chloride of potassium. Towards the end of the process, unless it is stopped, in time, the heat will be sufficiently great to melt the glass.

158. Oxygen may be procured, with great facility, by heating together two parts, by weight, chlorate of potash, and one part, peroxide of manganese.—The latter seems merely to favour the formation of gas-bubbles, but is not acted upon, itself. Other inorganic powders—black oxide of copper, for example—would answer as well for the purpose.

159. Oxygen is a colourless, tasteless, and inodorous gas; it is always electro-negative [gal. 63]: and is a non-conductor of electricity. Its specific gravity is 1.1056;—100 cubic inches of it, weigh 34.2865 grains. Water absorbs about the one-thirtieth of its bulk of this gas. It is not inflammable, but supports combustion, and with great energy, when in a state of purity.—If a taper, which has just been extinguished, the wick being still red hot, is introduced into oxygen, it will be immediately relighted. Charcoal, and phosphorus, in a state of ignition, burn brilliantly in it. If steel wire is formed into a helix, and a bit of thin iron turnings, which has been dipped in melted sulphur, is placed on one end of it and ignited, it will burn in a jar of oxygen, with great splendour, and the emission of vivid sparks.—If these precautions are taken, the experiment will be successful, even though the gas is not quite pure.

160. COMBUSTION, to the ordinary observer, appears to be the partial, or total annihilation of the substance burned. But, though a portion, or even the entire of it, disappears, it becomes invisible, only by giving rise to combinations which cannot indeed be seen, but are not the less real—since all of them may be collected, and examined. Chemically speaking, combustion is a union of the elements of the combustible, with the supporter of combustion—the latter being, in most cases, oxygen.

161. It was once thought that a substance, when burned, lost what was called *phlogiston*;* and the increase of weight, which is sometimes the consequence of combustion, was explained, by the gratuitous assertion, that phlogiston was the cause of levity.

162. The affinity exerted, during combustion, is, in many cases, so powerful, as to evolve heat, and even light. It is difficult, however, to account for these; since the ignited body occupies, after the combustion, a larger space than before;—and, by consequence [heat 79], cold, rather than heat, should be the result. The difficulty cannot be removed, by saying that

* *Phlego*, I burn. *Gr.*

bodies having a less specific heat are formed: since—as, when gunpowder is exploded—the specific heat of the compounds generated, is often greater than that of the combustible: and, in no case, is the diminution so considerable, as to account for the phenomena. The more violent the combustion, the greater the heat, and the more intense the light—which being, at first, blue, passes, as the temperature is increased, through various tints, until it finally becomes of the most dazzling whiteness. Heat and light are produced, by means of other supporters, besides oxygen:—they may be caused, even by the union of a combustible, with what is not ordinarily considered as a supporter. Thus, if sulphur is boiled in a matrass and, when the latter is filled with its vapour, a bit of copper leaf is introduced, great heat, and a brilliant light will be perceived [14]; and sulphuret of copper will be the result. On the other hand, perceptible heat and light do not necessarily accompany combustion:—this, as we shall find, is illustrated by the process of bleaching. Heat may be evolved without light—as in respiration; indeed, though not always perceptible, there can be little doubt that it is invariably the consequence of combustion. It will not be accumulated sufficiently to become apparent to the senses, unless the combustion is, to a certain degree, energetic.

163. Several conditions are required for perfect combustion. First, a combustible and a supporter are, evidently, indispensable:—the most inflammable substance, or the most powerful supporter cannot, of itself, give rise to combustion. Water extinguishes fire, simply, by placing the combustible, out of contact with the supporter. Hence, persons whose clothes unfortunately take fire, should, instead of running about, and thus fanning the flame, wrap themselves up, at once, in a carpet, &c.—to exclude the atmospheric air. Fire, in a chimney, is extinguished, by a wet sack, &c., placed over the top of it—the supply of air being cut off. Combustion may be carried on, even under water, if the combustible and supporter remain, notwithstanding, in contact:—for, as I have already stated [124], phosphorus may be burned, under that fluid. Sometimes the combustible and the supporter are found in the same substance—as, for example, in gunpowder.

164. Secondly, the combustible and supporter must be in the proper proportions [9].—If either is in excess, some of it will be left, and the combustion will be imperfect. The great degree of perfection, which has of late years, been given to lamps and furnaces, is principally due to a careful application of this principle, by securing a proper supply of atmospheric air—and therefore of oxygen. In an ordinary candle, the atmospheric air merely surrounds the flame; in an argand lamp, and candles with hollow wicks, air is supplied to the *interior* of the

flame. If this supply is interrupted, smoke will immediately be emitted. The supply of air to apartments is sometimes so limited, on account of the tightness of the doors and windows, that there is not enough even to maintain a draft in the chimney [steam 15], which, consequently, smokes.

165. *The Bude burner*, is constructed, in accordance with this condition. It consists of two or more annular tubes, furnished at the top with a number of apertures, from which the gas issues: each of them is raised higher, than that which is outside of it: and all are connected with one pipe. The light, from these circles of flame, is thrown in the proper direction, by means of reflectors. The *Bude light*, is produced, by conveying oxygen into the inner space of an argand lamp, so as to bring it in contact with the interior of the flame.

166. In the domestic fire, the burning fuel is merely surrounded with atmospheric air; but in the furnaces of steam-boilers, &c. [steam 18], it cannot enter the flue, to supply that which ascends, on account of its rarification, without passing through fuel in a state of ignition; and, as the velocity, with which it moves, is dependent on the draft, a current is formed, which produces the effect of a powerful bellows.—It is on this principle, that a common fire is kindled rapidly, by means of the blower.

167. Thirdly, the combustible and supporter must be properly mixed.—The burning fuel, in an ordinary grate, is surrounded with abundance of oxygen: and yet a large quantity of smoke escapes, through the chimney. A bellows renders the fire more energetic, by bringing the combustible and the supporter fully into contact.—One of the most important points, in the manufacture of gunpowder, consists in carefully mixing the ingredients. When the combustible and supporter are very well blended, the resulting extremely rapid combustion is termed “an explosion.” Combustion may often be produced, by an intimate admixture, when it would not otherwise take place. Thus, carbon, in a finely divided state, will ignite, of itself:—this has, sometimes, caused gunpowder mills to be destroyed. Also, if oxide of iron, of nickel, or of cobalt, is reduced, at a low temperature, by a stream of hydrogen, the particles of the reduced metal, being extremely minute, will take fire spontaneously in the atmosphere. The button in the interior of an argand burner, and often, the very shape of its glass—or metallic—chimney, contribute to throw the air into the flame, and mix it with the burning gases. This object is kept in view, also, in well-constructed furnaces.

168. Lastly, the combustible and supporter must be at a proper temperature.—Charcoal, at ordinary temperatures, will remain unchanged, for an indefinite period. The smoke escaping

from a chimney, becomes, after a while, thoroughly mingled with the atmospheric air: but it is not ignited, since its temperature has become too low, for that purpose. Damp fuel does not burn well, because a considerable portion of the heat is carried off, in the water which is vaporized. Hence, badly dried peat gives out but little caloric. Even fuel, apparently dry, may contain a large quantity of moisture.—In recently felled wood, from one-fifth to one-half its weight is water. Wood exposed to the air, for nearly a year, has been found to contain from 20 to 25 per cent. of that fluid. Wood charcoal, several years old, and kept for six months in a warm room, afforded 17 per cent. water. With a proper supply of air, at a proper temperature, the smoke *must* be entirely consumed. When coal is first thrown into the furnace, it is placed just within the door, and is coked by the fuel near it, already in a state of intense ignition [steam 14]. The gases, as they pass off, mix with the atmospheric air—of which a proper supply has been secured in the construction of the furnace—and, being at the requisite temperature for combustion, they inflame in their passage over the burning coals. In some recently constructed gas burners, which give a brilliant light, all these conditions are properly attended to: and the air, supplied to both the interior and exterior of the flame, is previously heated, by passing through wire gauze, fixed underneath it.—This gauze, also, tends more fully to mix the gases.

169. The temperature, at which combustion occurs, generally affects the nature of the resulting compounds.—When phosphorus is burned at that of the atmosphere, it takes three atoms of oxygen: but, when at a higher, five atoms. Alcohol, combined with oxygen, at ordinary temperatures, forms acetic acid: at those which are higher, carbonic acid and water.

170. If the combustion is very slow, the caloric may be dissipated as fast, or nearly as fast, as produced.—Nevertheless, a certain amount of time is required, for the economical combustion of fuel. Hence, the largest amount of heat is, practically, derived from the combustion of hard woods: though it should be obtained, from the soft—since those which have the greatest excess of hydrogen, above what is required for combination with the oxygen, ought to give the most heat. For, a given quantity of hydrogen, requires three times as much oxygen to burn it, as the same weight of carbon:—and it is tolerably certain, that the heat given out in combustion, is proportional to the oxygen, which enters into chemical union. The hydrogen, therefore, ought to produce three times as much heat, as the carbon. Generally speaking, however, furnaces are so constructed, that the heat will not be properly absorbed, if generated, with too great rapidity. If the lighter woods are

used, large quantities of flame are produced, by the combustion of compounds of carbon and hydrogen; and less carbon is left, to be burned when the flame has ceased. Should, however, a very intense fire be required—as, in porcelain furnaces—the softer woods are preferred: but, to get from them as much heat as possible, proper arrangements must be made.

171. RESPIRATION.—A slow combustion is going on, perpetually, in the animal body. Atmospheric air, which is drawn into the lungs, by what is called “inspiration,” is expelled, in a very different state, by “expiration.” During inspiration, oxygen is absorbed, and is carried by the blood, through the entire body: during expiration, the carbonic acid, taken up by the blood in its passage through the body, is evolved. A uniformity of temperature is secured, by the combustion being carried on in every portion of the body:—without this, one part might be intensely cold, while another would be inconveniently hot. Venous blood which is of a dark colour, is, by giving off carbonic acid and absorbing oxygen, changed into arterial blood which is of a bright red. This change may be effected, even out of the body, by exposing the blood to air, or what is better, to oxygen—particularly if it is agitated.

172. The blood is admirably adapted for absorbing, either carbonic acid, or oxygen.—It contains tribasic phosphate of soda having two atoms of fixed base ($\text{PO}_5 + 2\text{NaO} + \text{HO}$): a salt which absorbs carbonic acid with great avidity, but gives it all off again, on exposure to the air. Some of the common salt taken as food, changes the tribasic phosphate of potash—which renders the juice of flesh decidedly acid—into tribasic phosphate of soda; and the chloride of potassium formed, passes off in the urine. Blood is the only animal substance which has been found to contain iron: its colour being due to a salt of that metal, of which I shall speak hereafter. The red particles carry oxygen—as peroxide of iron—to the most remote portions of the body: and this peroxide, meeting with hydrogen, and with carbon, in the nascent state—both which have a strong affinity for oxygen—yield up to them the oxygen required for combustion. The iron is changed from *per* to *prot*-oxide—water being formed, which passes off at the surface, and carbonic acid, which is carried away by the blood, and evolved in the lungs.

173. It may be easily proved, that carbonic acid is given out from the lungs, by transmitting the expired air through lime water—which will soon be rendered turbid, on account of the carbonate of lime that is produced, and remains suspended in it. A healthy man spoils, in twenty-four hours, about 726 cubic feet of atmospheric air:—the combustion of three ounces of

charcoal would do the same. The absorption of oxygen, by the blood, was considered by Fourcroi, and other chemists, as necessary "to *irritate* the heart:" and to change the chyle from white to red, by peroxidizing the iron. They attempted to account for the equable temperature of the animal body, notwithstanding that—in their opinion—the combustion took place only in the lungs, by arterial having "greater capacity for heat," than venous blood.

174. A correct idea of the process of respiration, leads to an easy mode of explaining several very important facts, which, otherwise, are scarcely intelligible. Thus, in a hot climate, where cold rather than heat is necessary, the food consists principally, of substances—such as fruits—which contain little else than water; and which, so far from contributing to raise the temperature of the body, actually reduces it, by afterwards, to a great extent, passing off, in the form of vapour. In cold countries, on the contrary, the food—meat, for instance—is rich in carbon, and other highly combustible matter. And the Esquimaux, in gloating over their tallow candles and train oil, as the greatest delicacies, are only complying with an instinct, which leads them to select that nourishment which is best suited to their condition. One of the reasons, on account of which, bleeding is advantageous in inflammation, &c., is, that the red particles—which may be termed the "oxygen carriers"—being diminished, the supply of oxygen throughout the body is lessened; and, in the same degree, the evolution of heat. And, further to prevent combustion as much as possible, food rich in combustible matter, or that which is likely to augment the quantity of red particles, is carefully avoided.

175. It would seem that vital heat, and muscular energy, are simultaneously developed, by combustion within the body: and their *simultaneous* production appears to be necessary, for good health. Hence, when liquids containing alcohol are used, heat is generated, not as it should be, by a change of the tissues, but by the combustion of alcoholic vapour. For, alcohol has the peculiar property, of passing freely through the body, in a state of minute division—which [167] is highly favourable to chemical combination; and it is not, like other food, assimilated, by the process of digestion. It was found, by Prout, that alcohol and fermented liquors diminish the amount of carbonic acid, formed by respiration. The blood, therefore, is robbed of that oxygen, which should have gone to effect a gradual, and healthy change of the tissues: and the combustion—being due to a substance which is unconnected with the body—is the cause of heat, but not of muscular energy. The effects of this are obvious, in those who drink to excess:—They have not the proper digestive power, and are

visited with all the evils, which ought naturally to flow from the want of a proper amount of muscular vigour.

176. Exercise accelerates the action of the lungs, increases the amount of combustion—and, consequently, the quantity of heat produced : but, as it causes the tissues to be more quickly consumed, it renders their more rapid replacement necessary—and, thus, increases the appetite.

177. The fat of animals, is a store of combustible matter, destined to be used on extraordinary occasions. It soon disappears in starvation ; and, after it, the muscular flesh :—but, the tendons are not consumed, in any extreme of want. Hybernating animals carry with them to their winter retreats, as much fat as is sufficient to support a languid existence, which expends so little energy, and requires so small a quantity of heat. As might be expected, persons soon die, under the influence of both cold and hunger.—For, the effort made by the body, to meet the demand arising from increased combustion, renders the consumption greater, and a supply still more necessary.

178. The respiration of reptiles by means of tubes, and of fishes by means of gills, is founded on the same principle as that which is effected in the lungs. And it is worthy of remark, that the air which is disengaged from water by heat, is richer in oxygen than the ordinary atmosphere—since it contains thirty per cent. of that gas. This, probably, is intended to facilitate respiration, carried on by a comparatively imperfect apparatus. The low temperature, which accompanies the less perfect respiration of the lower orders in the animal kingdom, is what ought naturally to be expected. Vital heat is, in human beings, sensibly affected by imperfections in the respiratory organs, arising from disease or otherwise :—also, by the rapidity, or slowness of respiration, and by the quantity of red blood.

179. Carbon is not separated from the blood, by the agency of the lungs only. A large portion of it is removed, in the shape of bile, by the liver—the action of which has, therefore, been termed “*hepatic** respiration;” and, in some respects, its functions are subsidiary, to those of the lungs.

180. HYDROGEN :†—*symb.* H ; *equiv.* 1. It was described by Cavendish, as “inflammable air,” in 1776. It forms, by weight, one-ninth, and by measure, two-thirds of water ; and constitutes a large portion of animal and vegetable substances. Hydrogen may be obtained, in a variety of ways. It will be evolved if iron, or zinc, is dissolved in dilute sulphuric acid, sulphate of iron, or of zinc, being left in solution. ($\text{SO}_2 + \text{HO}$)

* *Hepar*, the liver. *Gr.*

† *Hudôr*, water ; and *gennao*, I produce. *Gr.*

+Fe=(SO₃+FeO)+H; and, (SO₃+HO)+Zn=(SO₃+ZnO)+H. The acid must be diluted, since its strong affinity for water will not allow the latter to be decomposed, unless it is present to a certain amount; also, sulphate of the protoxide of iron is not soluble in strong sulphuric acid. The gas obtained, is more pure, when zinc is employed. We may obtain hydrogen, likewise, by acting on a metal with hydrochloric acid (HCl):—hydrogen is evolved, and a chloride of the metal is left in solution. When zinc, for example, is used, $HCl+Zn=ZnCl+H$.

181. Hydrogen is a colourless gas; and, when quite pure, has neither taste nor smell. It is the lightest substance known, its specific gravity being 0.0693:—100 cubic inches of it weigh 2.149 grains. On account of its lightness, it has been used for the inflation of balloons [hyd. 40]: but coal gas, though much heavier—its specific gravity being about 0.4—is now employed for the purpose, from the ease, and economy, with which it is procured. It is obvious that when coal gas is employed, to obtain a given amount of buoyancy, a balloon of large size is not, required. The difference between hydrogen and coal gas is however, so great as might be supposed: since the hydrogen used with large balloons contains water in solution, which adds very much to its weight. Considering its density, hydrogen is a high refractor. It is very sparingly soluble in water. It is inflammable, but not a supporter of combustion, nor of respiration—though it may be breathed for a short time, without any other consequence than rendering the voice shrill, and small [pneum. 65]. This might be expected, from the diminished density of the vibrating medium, acted on by the organs of the voice.

182. We may prove that it is inflammable, but does not support combustion, by inverting a jar which is filled with it, and putting up into it, a lighted taper. The latter will be extinguished, when within the gas: but will be re-lighted, as it passes through the portion which is in contact with the atmosphere—and which, therefore, has been inflamed. Since the gas is lighter than common air, it will remain in the jar, though inverted—for a lighter cannot descend through a heavier fluid [hyd. 43]. When hydrogen is pure, the flame it produces is colourless.

183. It appears, from the researches and reasonings of chemists, that although it seems to form acids, it, in reality produces salts—being, it is supposed, a highly volatile metal. According to this opinion, when iron, which has stronger affinity than hydrogen for chlorine, is acted upon by hydrochloric acid (HCl), the chloride of hydrogen is merely changed into chloride of iron (FeCl). If hydrogen is really a metal, it is easy to account for the amalgam formed, by means of the galvanic battery, with ammonia (NH₃) and mercury.—It would not be

the only metal, known in a state of very subtile vapour. The probability that hydrogen is a metal, is increased by the resemblance found to exist between the salts of water, and those of zinc, and of copper.

184. If the materials, used for evolving hydrogen, are placed in a gas-bottle, stopped with a cork containing a tube of glass—drawn out fine at the end which projects externally, and the gas, as it escapes, is ignited, what has been called the “philosophical candle” will be produced. And, when the flame is held within tubes of different diameters, and consisting of glass, metal, &c., musical sounds—not, however, of a very pleasing description—will be heard. They arise from the successive explosions which, in reality, constitute the flame, and which cause the air to vibrate within the tube. Since these explosions follow each other with a certain degree of rapidity, the effect on the senses of sight, and hearing, is [pneum. 75 : and opt. 203] continuous. The intervals of silence perceived, are due to the columns of hot and cold air not being completely in unison [pneum. 98]. It is necessary, before lighting the gas, to allow the common air within the bottle to escape : or an inconvenient, and even dangerous explosion will occur.

185. Hydrogen forms, with oxygen, two oxides—water ($\text{HO} : 9\cdot0$), and peroxide of hydrogen, or oxygenated water, ($\text{HO}_2 : 17\cdot0$). It combines, also, with other elements :—the most important of the resulting compounds shall be examined, at the proper times.

186. WATER, *symb.* HO or *Aq.*; *equiv.* 9. It is always produced, when hydrogen is burned in atmospheric air, or oxygen. We can prove synthetically, as well as analytically, that it consists of oxygen and hydrogen, by holding a cold surface in the flame of burning hydrogen :—the water, formed during the combustion, will be deposited in drops upon the surface. Since it occupies a vastly less space than the gases which constitute it, the collapse of the air explains, to a certain extent, the noise heard when an explosive mixture is inflamed—as, for example, when the electrical pistol is fired, and the bladder [elect. 81, and 82] is burst. A lighted taper, applied to an aperture made in the bladder by a pin, would have produced the same effect as the electric spark. Such an experiment exemplifies the danger, which must arise, when hydrogen, or certain of its gaseous compounds—such as coal gas, or the vapour of ether, which also form, with oxygen, or atmospheric air, explosive compounds—are brought in contact with a lighted candle.

187. *Davy's lamp.*—Davy was led to the principle of his safety-lamp, by finding that if two bladders are filled with an explosive mixture of gases, and are connected by a tube of a sufficiently small diameter, the explosion of one will not pro-

duce an explosion of the other bladder. The lamp, which bears his name, was invented by him to secure miners, &c., from the dangerous accidents, to which they are exposed. It depends on the fact, that flame—which is gas at a white heat—will not pass through small tubes, or apertures, such as are formed by the wire-gauze, with which the “safety-lamp” is covered. For it is cooled down, by the angles and edges of the gauze; and, even if the latter becomes red hot, it continues incapable of igniting the mixture—which is gradually, and without any risk, consumed within the lamp. The intense heat will, however, if the mixture is highly explosive after a while oxidate the gauze, and make it fall to pieces:—an explosion would then ensue. In such cases, the flame of the lamp is first extinguished; and the inflammable gases burn on the interior of the gauze.

188. A current of ignited gases, may be made to pass so rapidly through the gauze, as not to be sufficiently cooled to prevent explosion.

189. The destruction of life, consequent on explosion in mines, arises, in many instances, from the subsequent want of oxygen, and the enormous quantities of carbonic acid: from the high temperature, often due in a great degree to ignition of the coal dust in the passages: and from the terrible tempests produced. When the mixture of gases, contains more than fourteen or less than seven volumes of atmospheric air, an explosion cannot occur.

190. If oxygen and hydrogen, in the proportions which constitute water, are thrown, during combustion, on any substance, they form what is called the oxy-hydrogen blow-pipe [103]: and afford an intense heat. If their flame is thrown upon lime, or chalk—which, under its influence, soon becomes lime, a light of the most dazzling brilliancy is emitted. It is called the “oxy-hydrogen lime-light,” [opt. 56: and gal. 56,] or “Drummond’s light”—since we are indebted for it, to the late Mr. Drummond, who used the light, afforded by some of the earths, when intensely heated, in geodetical observations: and* suggested its application to lighthouses. For the former, he preferred a stream of oxygen, thrown on the burning vapour of alcohol; and, for the latter, a mixture of oxygen and hydrogen, in combustion. A jet of oxygen, thrown on the flame of a spirit lamp will give a very great heat, and the compound flame thrown on lime, an extremely brilliant light. The Drummond light has been visible, at the distance of, at least, seventy miles. Its brightness is due to the fact, that different substances, emit, at the same temperature, light of very different intensity. Thus, in the experiment already mentioned [184], while the flame of

* Phil. Trans. 1826.

the burning hydrogen is scarcely perceptible, the extremity of the glass tube whence it issues, though not more strongly heated, is red. The intense light, emitted by certain solids raised to a high temperature, enables us to understand why hydrogen combined with carbon, gives a more brilliant light, though less heat, than hydrogen by itself. For, the elements of water, having the stronger affinity, will unite, before there is sufficient oxygen present to combine also with the carbon:—the latter will, therefore, be precipitated in the flame, and intensely ignited. If there is air enough—as in the argand burner [164]—it will, as it ascends, gradually combine with oxygen. Hence the middle of the flame will give carbon; but the bottom or top of it none. The same principle explains why zinc, or phosphorus, burns with such splendour.

191. Great care must be taken, in the combustion of oxygen and hydrogen, that the gases do not unite, except in small quantities, and just before being inflamed. Many ingenious contrivances have been devised, for security against the danger of their explosion.—Fine wires are placed lengthways in a tube of metal: and the interstices, which act as tubes of extremely small diameter, are still further diminished, by driving a plug strongly into the middle of the wires. This apparatus, however, impedes the passage of the gas considerably, and it will not prevent explosion, unless made with very great care. Sometimes the mixed gas is conveyed through the water with which a small vessel is partially filled:—fluid is thus interposed between the flame and the reservoir. If the small quantity over the water should explode, no mischief can occur, since either the vessel is made very strong; or a cork—which acts as a kind of safety-valve—is merely blown out. Very commonly, the hydrogen is placed in a gas-holder [fig. 337], and the oxygen in a similar one of half the size—the two vessels being connected, by means of an arched tube, the extremities of which are attached, respectively, to the union joints [105], placed on the upper ends of the tubes passing down through their centres. When water is poured into a funnel, inserted into the highest part of the arched tube, it enters each vessel, and forces out the gases through the cocks—one of which is seen, at P, fig. 337: whence they are conveyed to the jet, and are mixed just before being inflamed. As the two columns of water in the gas-holders are of the same height, the pressures are constant and equable [hyd. 8]: and there is no tendency in either gas to pass into the other vessel, and thus form an explosive mixture.

192. The mutual affinity of the elements of water, gives to us a means of reducing certain oxides. Thus, if a stream of hydrogen is passed through heated oxide of copper, water and

metallic copper will be the result. This, as we shall find, enables us, in the analysis of organic substances, to estimate the quantity of hydrogen which they contain.

193. If a stream of hydrogen is thrown on spongy platinum—procured by dissolving platinum in a mixture of nitric and hydrochloric acid, then precipitating it with sal-ammoniac, and heating the precipitate—it unites with the oxygen of the atmosphere so rapidly, that it causes the platinum to become sufficiently hot to set the gas on fire. This principle has been used, as means of obtaining light, instantaneously. Faraday has remarked that if platinum is connected with the positive, and, sometimes, even with the negative pole of a galvanic battery, it will afterwards cause the constituents of water to combine. The same effect will be produced if it is rendered perfectly clean with sulphuric acid, and subsequent washing in distilled water. This property—which has been shown, by Dulong, and Thenard, to belong to all the metals, earths, &c.—arises, according to Faraday, from the attraction of those substances for the gases: the particles of which are thus brought within the sphere of each other's attraction. For a similar reason, the presence of a solid body facilitates crystallization [heat 47]. The combination of the gases is always accompanied by the evolution of heat, and, often, by explosion.

194. A substance in the state of decomposition, will cause the mixed gases to combine. This effect is due to a chemical principle, I shall notice hereafter:—the inertia of the molecules is overcome, by an external force, derived from actually existing chemical action. The same result is obtained, whether or not, carbonic oxide—which is found to arrest the action of spongy platinum—is present.

195. No natural water is quite pure; since it always holds in solution the substances it has carried with it, from the strata through which it has passed. Alkaline waters are those which contain alkalis:—such are the geysers in Iceland. Saline waters contain the neutral salts. Sulphurous waters, contain sulphuretted hydrogen, or the sulphuret of a metal, &c. Chalybeate waters, contain carbonate of lime, or carbonate of iron, dissolved in the carbonic acid, which is in the water.—When the oxide, belonging to the carbonate of iron, is peroxidated by the oxygen of the atmosphere, it can no longer remain in combination with the carbonic acid. It is, therefore, precipitated: and constitutes the red sediment, which is observed in chalybeate springs, and the streams, issuing from them.

196. Water is capable of dissolving a variety of substances, to a greater or less extent [41]. It will leave one substance to combine with, or dissolve another.—Alcohol will precipitate nitre from water holding it in solution. Hydrochloric acid will,

in the same way throw down chloride of barium, by combining with the water which dissolved it.

197. Water is capable, also, of absorbing many gases; among others, atmospheric air [steam 53]—which is given out again by boiling. Since the air, which is required for the respiration of fishes, &c., is obtained from the water, it is sometimes necessary to break the ice, that it may be renewed:—without this precaution, the fishes would die. The presence of atmospheric air in water, greatly hinders the absorption of other gases:—for a small quantity of a sparingly soluble gas will expel, or prevent the absorption of a large, but corresponding, quantity of a very soluble gas. Fish will not live in the lakes of mountainous regions—as the water does not retain enough air, in solution.

198. PEROXIDE OF HYDROGEN:—*ymb.* HO_2 ; *equiv.* 17. This is a very curious, though not a very important substance. To obtain it, pure barytes is peroxidized, by heating it along with an equal weight of chlorate of potash.—When oxygen begins to be disengaged from the chlorate, a brilliant red glow commences at one point, and spreads over the whole mass. The hydrate of the deutoxide of barium ($\text{BaO}_2 + \text{Aq.}$) is separated, by washing, from the chloride of potassium: and is added to dilute hydrofluoric acid, until acidity is removed. Fluoride of barium, and peroxide of hydrogen are the results. $\text{HF} + \text{BaO}_2 = \text{BaF} + \text{HO}_2$. The fluoride and excess of peroxide of barium are separated, by filtration, from the dilute peroxide of hydrogen; which is then placed under an exhausted receiver along with sulphuric acid [heat 93], to remove the water. If left too long under the receiver, the peroxide itself will evaporate.

199. Peroxide of hydrogen is a thick colourless and caustic liquid, of a disagreeable taste. It parts with oxygen very easily; and, therefore, bleaches, &c.: and is very energetic, unless greatly diluted. Many solids violently resolve it into water, and 475 times its bulk of oxygen: and often without being changed themselves—which is particularly the case with peroxide of manganese. Sometimes the oxygen of the peroxide instead of becoming free, enters into combination—as when oxide of lead is used. It is decomposed rapidly by fibrine; but not at all by albumen. Its specific gravity is 1.452. If kept long, even diluted, oxygen is liberated spontaneously, until at length nothing but water remains.

200. COMPONENTS OF ATMOSPHERIC AIR; NITROGEN:—*ymb.* N; *equiv.* 14.02. Atmospheric air consists, principally, of nitrogen and oxygen. The former has been already examined. Nitrogen, which is also called “azote,”† was discovered by Rutherford, of Edinburgh, in 1772; and was ascertained to

* *Nitron*, nitre; and *gennao*, I produce. *Gr.*

† *A*, a privative particle; and *zōē*, life, *Gr.*:—from its being incapable of supporting life.

be an element of atmospheric air, by Lavoisier, in 1775. It is found in great abundance: and constitutes about four-fifths of the whole atmosphere: as, also, a large portion of many animal, &c., substances. It may be obtained by several processes. If a receiver is inverted over a capsule, floating on water, and containing burning phosphorus, the oxygen of the common air will combine with the phosphorus, and form phosphoric acid (PO_5). The latter will be, at first, in the state of white fumes—consisting of minute crystals, suspended in the nitrogen: and, after a little while, on account of its deliquescence, will be dissolved by the water in which the receiver stands. Nothing will then be left, along with the nitrogen, except some vapour of phosphorus, and a little carbonic acid—both which may be removed, by passing the mixture through a solution of caustic potash: and some aqueous vapour—which would be taken away, by transmitting the gas through fused chloride of calcium, or strong sulphuric acid.

201. Nitrogen is colourless, tasteless, and inodorous. Its specific gravity is 0.976:—100 cubic inches weigh 30.2674 grains. Its characters are merely negative.—It is not a combustible, in the ordinary sense; though if it is mixed with hydrogen, and set on fire, a green flame will be produced, and the water derived from the combustion, will be found to contain nitric acid (NO_5). The latter will be formed, also, by passing electric sparks through moist atmospheric air: as may be proved by wetting litmus paper with the solution of an alkali, and taking a succession of sparks with it.—The paper will be reddened, at the point where the sparks are taken: and, if it is dried, and ignited, it will show—by burning like touch-paper—that nitrate of potash ($\text{NO}_5 + \text{KO}$) has been formed. Nitrogen is not a supporter of combustion—nor, consequently, of respiration. I may take this opportunity of remarking, that irrespirable gases are of three kinds. The “narcotic,” which produce torpor—as sulphuretted hydrogen: the “irritant,” which produce inflammation of the lungs, &c,—as ammonia; and the “neutral,” which are injurious, only from the absence of oxygen—as nitrogen. The larynx closes spasmodically against certain gases: which are then said, in ordinary language, to “stop the breath.” This happens with chlorine, carbonic acid, &c. When such gases are diluted, to a certain extent, with common air, they enter the lungs: and cause, as the case may be, an irritant, or a narcotic effect.

202. Some—among others Sir H. Davy, and Berzelius—have supposed nitrogen to be a compound substance. The chief argument, in favour of this hypothesis, is that ammonia (NH_3), as I have already remarked [183], will, under the influence of the galvanic battery, along with mercury, form an amalgam. Which would seem to indicate that NH_4O ($\text{NH}_3 + \text{HO}$) is the

oxide of a metal : unless it is admitted, that so light a body as hydrogen is metallic [183].—This argument is, however, questionable; since Gay, Lussac, and Thenard assert that, even though moisture is absent, the amalgam will, on breaking contact with the battery, resolve itself into ammonia, hydrogen, and mercury. Also, it has been considered, by some chemists, as very unlikely, that all the nitrogen found in the muscles of graminivorous animals, is derived, as nitrogen, from vegetables—which, therefore, they suppose must contain its elements. Whence it would follow that it is a compound.

203. The affinities of nitrogen—except in the nascent state—are not very strong. It forms, with oxygen, nitrous oxide (NO : 22·02); nitric oxide (NO_2 : 30·02); hyponitrous acid (NO_3 : 38·02); nitrous acid (NO_4 : 46·02); and nitric acid (NO_5 : 54·02). It forms, with hydrogen, ammonia (NH_3 : 17·02). With chlorine, terchloride of azote (NCl_3 : 120·43), &c.

204. ATMOSPHERIC* AIR.—It is doubtful whether, or not, this is a compound, or merely a mixture:—the latter is the more probable. It is tasteless, inodorous, and, when in small quantities, without colour. It is a bad conductor of electricity. Being the standard of comparison for the gases, its specific gravity is represented by unity:—compared with distilled water, it is 0·00122. It is therefore, 820 times lighter than water, in ordinary circumstances; and 780 times lighter than that fluid, when at its greatest density—that is, at a temperature of $40\cdot5^\circ$. If the barometer is at 30 inches, and the thermometer at 60° , 100 cubic inches of atmospheric air, free from moisture and carbonic acid, weigh 31·0117 grains. The height of the atmosphere has been estimated at 45 miles: and its temperature decreases one degree, for about every 352 feet of ascent. This decrease is due to its greater distance from the earth, which heats it by contact;—also, its specific heat being increased by its rarity [heat 79], it requires a larger quantity of caloric, to raise it to a given temperature. Poisson supposes the air, in the upper regions, to be so cold as to be actually frozen: in which case, our earth and atmosphere would be contained in a shell of frozen air. But the cold of the planetary spaces has been shown, by Fourier, not to be lower than -57° , which is met with, at Melville Island, in winter, and is often exceeded by artificial means; while, at the lowest temperature we can produce, atmospheric air does not show any tendency to become even a fluid—much less a solid.

205. The quantity of oxygen in the air, is constant.—Hence, to suppose that the salubrity of a climate depends on the amount of that gas, contained in its atmosphere, is erroneous. As to the miasmata which cause, or disseminate disease, they

* *Atmos*, vapour; and *sphaira*, a sphere. *Gr*.

have, hitherto, proved too subtle for chemical analysis. An instrument for ascertaining the quantity of oxygen, in the atmosphere is termed a "eudiometer."* It has been variously constructed. Spongy platinum [193], mixed with clay—to prevent its action from being too sudden—and let up into a graduated glass jar, which contains common air and hydrogen, and stands over mercury, forms a simple and very excellent one. The diminution of bulk, arising from the union of hydrogen with the oxygen is to be noted: and one-third of it is to be considered as having been occupied by the oxygen which has disappeared—and which belonged to the atmospheric air, under examination.

206. Another kind of eudiometer, consists of a glass tube, bent until the two parts are parallel, and hermetically sealed at one end. Two fine platinum wires are inserted into opposite sides, near the sealed end—the glass being fused around them. An ascertained quantity of common air is placed, along with some hydrogen, in the tube, and outside of it mercury—some space being left, next the open end. When the latter is closed with the thumb, and an electric spark is transmitted through the wires, so as to explode the gases, the elasticity of the air next the thumb, will prevent the mercury from being blown away. After the explosion, the diminished space occupied by the gases—the residue of which consists of hydrogen and nitrogen—may be determined. One-third of what has disappeared was oxygen.

207. The proportion of nitrogen, in the atmosphere, has been variously estimated:—it is about four measures in five. If it is replaced, by an equal quantity of hydrogen, life will be supported: but the animal will fall asleep.

208. The rarity of the atmosphere, in hot climates, causes a smaller quantity of oxygen to be contained in a given space:—hence the lungs, and their auxiliary the liver [179], are over-worked, in producing a given effect. And—according to a provision which makes that part of the animal body, thrown into more frequent, or energetic action, to increase in size—the liver becomes diseased, from augmented bulk. The rarity of the atmosphere, also, makes breathing painfully difficult, on very high mountains.

209. It is an object of interest, to ascertain if the gases, which constitute the atmosphere, are chemically combined, or only mechanically mixed.—Their proportions are favourable to chemical union: being about one to five, by measure: and one to three and a half, by weight. But the density, specific heat, &c., of the atmosphere, are the mean of those belonging to its constituents; and the synthetical production of it, gives rise to

* *Eu*, well or right; and *Dios*, *Gr*. A name for Jupiter, and applied also, to the air.

none of those changes, which, in a greater or less degree, are found to accompany chemical action:—there is no condensation: no evolution of heat: nor are any qualities subsequently perceived, which might not be expected from a mere mixture. The difference between the densities of the two component gases, is no obstacle to their mixture. For Dalton found that, if a heavier gas is placed in the lower of two bottles, connected by a tube, it will soon be equally diffused through both. This tendency—as was first ascertained by Priestly—is not prevented by the interposition of a membrane; and it extends even to fluids. The passage of gases or fluids, in this way, has been termed “endosmose,”* and “exosmose.”† Two currents are established between the gases or fluids of different densities: the lighter, generally, having a tendency to dilute the heavier. Dalton believed that vapours and gases diffuse themselves through space, as if each alone were present: and that they offer only *mechanical* obstacles to each other:—and he established his opinion, by an experiment already mentioned [heat 109]. He found that as much of the vapour of each was within the receiver, as if all the rest were absent.

210. The velocity with which gases diffuse themselves through each other, and, also, the times, required by them, for entering a membrane, or a porous body, are inversely as the square roots of their specific gravities.

211. Their tendency to diffuse themselves, through each other, may be illustrated, by closing a vessel, containing hydrogen, with a sheet of caoutchouc.—The hydrogen will pass out, more quickly than the common air will enter; and the caoutchouc will be bent inwards so much, that it will ultimately burst.

212. There occurs, in wine countries, a curious example of the ease with which gases permeate membranes, and animal tissues.—A poisonous wine, called “feather white wine,” is deleterious, merely because it is still in a state of fermentation, which is increased by the heat of the stomach. The disengaged carbonic acid penetrates through the body to the lungs, from which it expels the atmospheric air, and thus causes asphyxia. Inhalation of ammonia, is the best remedy for the effects of this wine.

213. Besides nitrogen, the atmosphere contains also carbonic acid (CO_2), ammonia (NH_3), and the vapour of water. Carbonic acid is found, even on the highest mountains: it is more abundant in summer, than in winter; at night, than in the day; and in gloomy, than in clear weather:—a moist ground succeeding rain diminishes its quantity. The ammonia of the atmosphere

* *Endon*, within; and *ōsmos*, impulse. *Gr.*

† *Ek*, out of; and *ōsmos*. *Gr.*

is derived from animal, and vegetable substances. Liebig ascertained its presence, by evaporating a large quantity of rain water, to which a little hydrochloric acid had been added.—Crystals of sal-ammoniac (NH_4Cl) were produced. He detected it also in snow water, by the addition of hydrate of lime. The amount of watery vapour, contained in atmospheric air, is determined by the principles of hygrometry [heat 95].

The relative quantities of the ordinary constituents of the atmosphere may, on an average, be considered as follow :—

	In 100 parts, by volume.	In 100 parts, by weight.
Oxygen,	20·935	23·146
Nitrogen,	77·418	75·567
Carbonic acid,	0·045	0·068
Vapour of water,	1·602	1·219
	<hr/> 100·000	<hr/> 100·000

Atmospheric air has never been liquefied.

214. *Ozone*. *—This substance, which, as I have already noticed [elect. 104], is present in the atmosphere surrounding an electrifying machine, is found also in the oxygen evolved from water, decomposed by the galvanic battery. Its nature has not yet been ascertained.—Air containing it, will, like chlorine, a substance we shall examine hereafter, liberate iodine from iodide of potassium; and it will change yellow, into red prussiate of potash. It is decomposed, or removed, by the presence of organic matters.

215. NITROUS OXIDE :—*symp.* NO : *equiv.* 22·02. It is obtained, by heating nitrate of ammonia ($\text{NO}_3 + \text{NH}_4\text{O}$), which melts into a liquid, at 300° : is decomposed at 350° : and is entirely changed, by heat, into nitrous oxide, and water. $(\text{NO}_3 + \text{NH}_4\text{O}) = 2\text{NO} + 4\text{HO}$.

216. Nitrous oxide is a colourless gas, of a pleasant taste, and an aromatic smell. Its specific gravity is 1·527 :—100 cubic inches weigh 47·3549 grains. It is absorbed, by an equal volume of fresh boiled water :—and hence, to prevent its being wasted, is collected over a saturated solution of common salt. It is nearly as good a supporter of combustion as oxygen—being decomposed, and yielding that substance to the elements of the combustible. It may be breathed, for a short time : and has a very extraordinary effect, upon many persons. Generally speaking, when inhaled, it causes great exhilaration of spirits, a flow of vivid ideas, very pleasurable sensations—not followed by the languor which succeeds every species of intoxication, and a great tendency to laughter. On account of the latter, it has been called the “laughing gas” of Sir H. Davy, by whom

* *Ozo*, I smell. *Gr.*

it was discovered. Its action, on persons of different temperaments is, however, various: but it is rarely disagreeable, and never dangerous—provided a pure gas is used. If the same portion is passed too frequently, through the lungs, its properties are entirely changed by respiration: and the carbonic acid, derived from it would, if inhaled, cause asphyxia [212]. The presence of sal-ammoniac in the nitrate of ammonia, would render the gas pernicious, by giving rise to the production of nitrous acid, and chlorine. Hence, the nitrate should be formed for the purpose:—about two ounces of it would produce gas enough to affect one person.

217. Nitrous oxide can be deoxidated, and pure nitrogen be obtained from it, by heating nitrate of ammonia, in a tubulated retort; and, when the salt melts, pushing down into it a bit of zinc, which has been previously attached to a copper wire, passing through a cork in the tubulature. Nitrous oxide and zinc, form nitrogen and oxide of zinc.
 $\text{NO} + \text{Zn} = \text{N} + \text{ZnO}.$

218. NITRIC OXIDE:—*ymb.* NO_2 ; *equiv.* 30.02. It is produced, when a metal is acted on with nitric acid. To obtain it, a mixture, consisting of equal volumes of water and nitric acid, is to be poured on copper filings, or small bits of copper: and heat is to be applied, until the action commences:—after which the gas will continue to be disengaged copiously. Nitric acid and copper, form nitrate of copper, and nitrous oxide.
 $4\text{NO}_3 + 3\text{Cu} = 3(\text{NO}_3 + \text{CuO}) + \text{NO}_2.$

When iron is dissolved in dilute nitric acid, without the evolution of gas, water and nitric acid are decomposed, oxide of iron (FeO), and ammonia (NH_3) being produced.
 $\text{NO}_3 + 3\text{HO} + 8\text{Fe} = 8\text{FeO} + \text{NH}_3.$

219. Nitric oxide is a colourless gas; but, since it cannot be brought into contact with oxygen without being changed, neither its taste, nor smell, if it have any, can be ascertained. Its specific gravity is 1.041:—100 cubic inches weigh 32.2832 grains. It is sparingly absorbed, by water at 60° . It is not a combustible; nor, except in a few instances, a supporter of combustion:—carbon and phosphorus, however, when vividly ignited, become more brilliant in this gas, which is decomposed, by the high temperature, into nitrogen and oxygen. Attempting to breathe it, causes a violent spasm of the glottis. It may be changed into nitrous oxide, by being left for some time in contact with moist iron or zinc filings.

220. HYPONITROUS ACID:—*ymb.* NO_2 ; *equiv.* 38.02. Of all the gases, nitric oxide, only, has the property, on being mixed with oxygen, of becoming an orange vapour: some of this vapour is hyponitrous acid. Oxygen, therefore, and nitric oxide are *tests* for each other. Hence, if we suspect either to

be present, we have only to introduce into it, a small quantity of the other—or of some gas which contains it, and our doubt will at once be removed.

221. Pure hyponitrous acid may be obtained, by mixing four measures of nitric oxide, and one of oxygen—both dry; and liquefying the resulting orange vapours, by cold. Liquid hyponitrous acid is the nitrous acid of continental chemists. Whether hyponitrous, nitrous, or nitric acid will be formed singly, or together, on mixing nitric oxide and oxygen, depends, not only on the relative quantity of the gases, but also on circumstances seemingly immaterial—such as the diameter of the tubes, &c., employed—the rapidity with which the mixture is made—the time allowed after mixing—the amount of agitation—and whether the oxygen is added to the nitric oxide, or the reverse, &c.

222. Hyponitrous acid, in the state of vapour, has a very disagreeable taste, and a suffocating smell; it is neither a combustible, nor a supporter of combustion. It is absorbed by water, giving rise to nitric acid, and nitric oxide. $3\text{NO}_2 = 2\text{HNO}_3 + \text{NO}$. If much nitric acid is present, nitric oxide is formed, and nitrous acid—which colours the fluid, to an extent dependent on the quantity. $2\text{NO}_2 = \text{HNO}_2 + \text{HNO}_3$. The specific gravity of this acid, in the state of vapour, has not been satisfactorily ascertained. At a temperature of 0° , it becomes a colourless, and, at -8° , a deep green liquid. Hyponitrous acid, in the fluid state, is highly volatile: and evaporates in the form of orange vapours. The acid properties of this gas, may be shown, by attaching a small piece of litmus paper to the interior of a jar, filling the latter with water, then inverting, and letting up into it four volumes of nitric oxide, and one of oxygen:—the moment the latter is introduced, the paper will be reddened.

223. Priestley discovered that water, holding hyponitrous acid in solution, becomes dark brown, and opaque, by the addition of sulphate of iron.

224. A compound, containing hyponitrous acid, cannot be produced directly; since that acid is decomposed, whether in the gaseous, or fluid state, by contact with water;—it may, however, be formed, indirectly, by keeping nitre ($\text{NO}_3 + \text{KO}$) melted for some time. Two atoms of oxygen will be given off, and hyponitrate of potash will be formed. $(\text{NO}_3 + \text{KO}) = (\text{NO}_2 + \text{KO}) + \text{O}_2$.

225. NITROUS ACID:—*ymb.* NO_2 ; *equiv.* 46.02. It is obtained, by heating finely-powdered and well-dried nitrate of lead ($\text{NO}_3 + \text{PbO}$), to full redness. The nitric acid separates from the oxide of lead; but, as it cannot exist without water, it is immediately decomposed into nitrous acid, and oxygen.

The red vapours, as they are evolved, are condensed into a liquid, by a mixture of snow and salt: and the free oxygen passes off. $(\text{NO}_3 + \text{PbO}) = \text{NO}_2 + \text{PbO} + \text{O}$.

226. Nitrous acid vapour is orange red; it is irrespirable, causing great irritation and spasm of the glottis. It supports combustion brilliantly; burning sulphur is, however, extinguished by it. Since one volume of it contains one volume of nitrogen ($=0.976$), and two of oxygen ($2 \times 1.1056 = 2.2112$), its specific gravity should be 3.1872 ($=0.976 + 2.2112$). The vapour, if passed into a jar of atmospheric air, will, on account of its greater specific gravity, displace the air. It cannot be collected over water, which changes it to nitric acid, and nitric oxide. $3\text{NO}_2 = 2\text{NO}_3 + \text{NO}$. This arises from the affinity of water for nitric acid. But, if this affinity is satisfied, by the presence of a sufficient quantity of that acid, the nitrous acid is not decomposed: and the fluid is bluish, bluish-green, green, yellow, or orange—according to the relative quantities of nitrous acid, nitric acid, and water. The nitric oxide formed by decomposition of the nitrous acid, escapes with effervescence—unless the quantity of water is small, in which case, the fluid merely becomes of a green colour. Nitrous acid cannot be collected over mercury, since it would be decomposed—the metal being oxidized.

227. Liquid nitrous acid has a specific gravity of 1.451 . It is nearly colourless at 0° : is orange yellow at 60° , and becomes a white crystalline solid, at -40° . It boils at 82° , producing a red vapour, which at 212° is quite black [opt. 112]. If the bottle which contains it is not stopped, it will evaporate rapidly, at 60° .

228. It was at first supposed, that attempting to unite this acid with bases, would merely give rise to nitrates, and hyponitrites:—and hence it was inferred to be only a combination of nitric and hyponitrous acids ($2\text{NO}_2 = \text{NO}_3 + \text{NO}$); but it has been ascertained that it is capable of forming salts.

229. NITRIC ACID:—*symb.* NO_3 ; *equiv.* 54.02 . It is obtained by pouring 98 parts, by weight of concentrated oil of vitriol ($\text{SO}_3 + \text{HO}$) on 101.14 parts of well-dried nitre [nitrate of potash; $(\text{NO}_3 + \text{KO})$]; and applying heat. The nitric acid distils over, and bisulphate of potash—double sulphate of potash and water $[(\text{SO}_3 + \text{KO}) + (\text{SO}_3 + \text{HO})]$ —remains in the retort. $(\text{NO}_3 + \text{KO}) + 2(\text{SO}_3 + \text{HO}) = [(\text{SO}_3 + \text{KO}) + (\text{SO}_3 + \text{HO})] + (\text{NO}_3 + \text{HO})$. In the commencement of the process, orange vapours are evolved:—for, common salt (NaCl) being present in the nitre as an impurity, hydrochloric acid (HCl) will be liberated by some of the sulphuric acid: and, as we shall find hereafter, will be decomposed by, and decompose a portion of

the nitric acid. Likewise, some of the nitric acid is decomposed, by the sulphuric acid combining with its water. At the end of the process, also, orange vapours will be evolved, from some of the nitric acid being decomposed, on account of the high heat:—when this occurs, the process should be stopped.

230. It depends on the quantity of sulphuric acid used, whether sulphate, or bisulphate of potash will be left in the retort.—It is better to form the bisulphate, since it is the more soluble, and may be removed without much difficulty: while the retort will, most probably, be broken in attempting to take away the sulphate. When enough sulphuric acid to form the bi-salt is employed, the nitric acid takes half its water, and is distilled off, at from 266° to 269° . By itself, it boils at 106.8° ; but all the acid would not, with that temperature, be separated from the bisulphate.

231. If only enough sulphuric acid to form sulphate of potash is used, the process is more complicated; for, then, only half the nitre is decomposed, and only half the nitric acid obtained—a mixture of nitrate and bisulphate of potash being formed, which is not decomposed so as to yield nitric acid and become sulphate, until the temperature rises to 400° . And, at first, a weaker nitric acid is disengaged, on account of the high heat decomposing some of it, the water of which goes to the rest. As the process advances, the acid becomes stronger: but towards the end, the very elevated temperature decomposes nearly the whole of it, into oxygen and nitrous acid—which [226] is dissolved by the nitric acid in the receiver, particularly when the latter is kept cool.

232. If the nitre is not well dried, before being used, the water, *mechanically* mixed with its crystals, would weaken the nitric acid. A small quantity of organic matter in the nitre, would decompose some of the acid; also the presence of a comparatively large quantity of sulphuric acid—which, before it would have time to unite with the potash, would take away some water.

233. Nitrate of soda ($\text{NO}_3 + \text{NaO}$) has almost entirely superseded nitrate of potash, in the manufacture of nitric acid:—it is cheaper; it affords a larger product; and does not require so high a temperature, nor so much sulphuric acid. 100 parts nitrate of potash, contain only 53.41 nitric acid: while 100 parts nitrate of soda contain 63.56.

234. When the sulphuric acid is cautiously poured into the retort, the nitric acid will be quite free from it. Any which may be present, however, and also any iron—generally found in the nitric acid of commerce—may be removed, by rectifying (re-

distilling):—they will be left behind, if the process is not carried too far. The apparatus, fig. 338, may be used, both in the manufacture, and rectification. Chlorine, if detected, may be separated by nitrate of silver, which will form water and chloride of silver—a white powder, from which the acid may be decanted.

235. Nitric acid has never been insulated:—that is, it has never been procured, except united with water, &c. It may, sometimes, be obtained, in combination with but a single atom of that fluid—its specific gravity then being 1.521. It is, generally, found to have a specific gravity of 1.500: in which case, two atoms of the acid are combined with three atoms of water. When its specific gravity is 1.35, it does not act on tin nor iron, unless they are touched with another metal, while immersed in the acid. It will not act on lead, or tin, if concentrated; but if it is diluted with water, violent action is, at once, produced. Nitric acid is a powerful oxidizing agent. This was sufficiently evident, when [119] it was poured on oil of turpentine:—water and carbonic acid were produced, with such violence, that ignition was the consequence. The deep red fuming acid—sometimes called the “nitroso-nitric”—imparts oxygen, with still greater facility than pure nitric acid. It may be obtained, by passing nitric oxide, into nitric acid. Part of the latter, yielding an atom of its oxygen, forms nitrous acid, which is absorbed by the remainder. $2\text{NO} + \text{NO}_2 = 3\text{NO}_2$.

236. Gold, platinum, iridium, rhodium, osmium, &c., resist the action of nitric acid—which, however, dissolves an alloy of gold and platinum. Gold may be separated from silver, by dissolving out the latter, with nitric acid—the process being termed “parting.” But if more than a fourth of the alloy is gold, it will, to a certain extent, protect the silver from the action of the acid. In such a case, silver must be added. This is called “quartation,”* the gold being made to constitute a *fourth* part of the mass.

237. Animal matter is decomposed, by nitric acid; and it stains the skin, and nails, a permanent yellow—the stain being rendered temporarily brighter by ammonia. It is sometimes used as a disinfectant: and a larger quantity of it may be inhaled, along with common air, in respiration, than of chlorine—which, also, as we shall find, is very efficient in destroying infection. Parliament gave £5,000 to the discoverer of the disinfecting power of nitric acid.

238. The facility with which this acid, even in combination, parts with oxygen, gives a considerable importance to some of the substances containing it: and may be exemplified by

* *Quartus*, the fourth. *Lat.*

throwing charcoal into red hot nitre. Detonation will occur and most brilliant combustion will take place, carbonate of potash being produced. Nitre is a very necessary constituent of gunpowder. The latter, when of good quality, is changed, by the explosion—that ought to be neither too rapid, nor too slow—into gases which fill 1,000 times the space, previously occupied by the powder. Many other substances are more powerful: but they explode so rapidly, that they would burst the gun, on account of their action not continuing long enough to overcome the inertia of the ball [mech. 6]. One part carbonate of potash ($\text{CO}_2 + \text{KO}$) one part sulphur and three parts nitre, form a mixture which explodes so violently that, if placed in a metallic spoon and heated, the spoon will be indented—or even perforated. Nitrogen, carbonic acid, and sulphate of potash are the results. $2(\text{CO}_2 + \text{KO}) + 3(\text{NO}_5 + \text{KO}) + 5\text{S} = 3\text{N} + 2\text{CO}_2 + 5(\text{SO}_3 + \text{KO})$. The quantity of gas is less than that produced by gunpowder: and its violent action is caused, by the speed with which ignition is communicated, through its entire mass. Rapidity of combustion is due to the sulphur; the charcoal furnishes the gas:—three parts nitre and one of charcoal, form a mixture which burns quickly, but without explosion: carbonate of potash is formed, carbonic acid and nitrogen being evolved. $2(\text{NO}_5 + \text{KO}) + 5\text{C} = 2(\text{CO}_2 + \text{KO}) + 3\text{CO}_2 + 2\text{N}$. More sulphur than is ordinarily used, would increase the strength of the powder; but would injure the fire-arms, by forming higher sulphurets of potassium—which part with a portion of their sulphur without difficulty. Sulphur, changed to sulphurous acid, or having no element in the powder with which it may combine, would evidently be very improper. Too much nitre, also, would be mischievous: but is not likely to be in excess—on account of its expense.

Nitrate of soda, being very deliquescent, cannot be substituted for nitrate of potash, in the manufacture of gunpowder.

239. Theoretically, gunpowder ought to contain one atom nitre, one atom sulphur, and either three or six atoms carbon: since these would be entirely converted into sulphuret of potassium, carbonic acid—or carbonic oxide—and nitrogen. It depends on the manufacturer, whether carbonic acid, or carbonic oxide shall be one of the results. $(\text{NO}_5 + \text{KO}) + \text{S} + 3\text{C} = \text{KS} + 3\text{CO}_2 + \text{N}$: and $(\text{NO}_5 + \text{KO}) + \text{S} + 6\text{C} = \text{KS} + 6\text{CO} + \text{N}$. If any carbonate of potash is formed, the effect of the powder is diminished; the increase of volume, produced by the explosion, not being so great.

240. The gases actually produced, during the combustion of gunpowder were ascertained, by Chevreul, and Gay Lussac, from specimens examined by them, to be—

	Chevreul.	Gay Lussac.
Carbonic acid,	45·41	53·00
Nitrogen,	37·53	42·00
Carbonic oxide,	00·00	5·00
Nitric oxide,	8·10	
Carburetted hydrogen,	0·59	
A peculiar gas, containing carbon, hydrogen, and oxygen,	8·37	
	<hr/> 100·00	<hr/> 100·00

241. When rocks, earth, &c., are overturned by gunpowder, if the quantity is properly adjusted, the effect is produced so gently, that the resulting sulphuret of potassium, and the non-permanently elastic fluids, have time to be condensed, and the permanent gases are cooled down, and partially absorbed—or they gradually escape: so that little noise or smoke, compared with the amount of powder, will be perceived. Similar causes diminish the noise, &c., of gunpowder, fired under water.

242. The flame, perceived at the mouth of the gun, is due to the hot sulphuret of potassium and combustible gases, coming in contact with atmospheric air, and causing a second combustion—sulphate of potash, carbonic acid, and water being produced.

243. We have no very good direct test, for ascertaining the presence of nitric acid; since the neutral, and most of the basic nitrates, being soluble in water, do not afford precipitates. It may, however, be recognised, by evolving red fumes, when brought in contact with a metal.—If the nitric acid is in combination, the red fumes are disengaged on heating the solution containing it in a test tube, along with some copper filings and oil of vitriol. In both cases, the nitric oxide, liberated by the metal [220], is changed into hyponitrous acid by the oxygen of the atmosphere: and in the latter, the sulphuric acid combines with the base of the nitrate. If hydrochloric acid is added to a liquid containing nitric acid, the mixture will dissolve gold. For hydrochloric and nitric acids will, as we shall find hereafter, produce nitrous acid, water, and chlorine—which dissolves the gold. $\text{NO}_5 + \text{HCl} = \text{NO}_4 + \text{HO} + \text{Cl}$. If the nitric acid is in combination, a chloride, also, will be obtained. $(\text{NO}_5 + \text{KO}) + 2\text{HCl} = \text{NO}_4 + 2\text{HO} + \text{KCl} + \text{Cl}$.—This test is not, however, decisive; since the presence of chloric acid (ClO_5) &c., also, would cause the gold to be dissolved. If there is added to a fluid containing nitric acid, as much of the solution of indigo in sulphuric acid, as will make it of a faint light-blue colour, adding a few drops of sulphuric acid, and subsequently boiling the mixture will bleach it or, if the quantity of nitric acid is small, will render it yellow: for, the nitric, liberated by the sulphuric acid, oxidizes the indigo.—But, other substances, particularly free chlorine, would produce the same effect. If a small crystal of green

vitriol [protosulphate of iron ($\text{SO}_3 + \text{FeO}$)] is placed in contact with a fluid, containing nitric acid—after it has been mixed with one-fourth of its volume of strong sulphuric acid, and has been allowed to cool—the portion surrounding the crystal will become of a dark olive brown colour. Some of the iron is peroxidated by the nitric acid: and the resulting nitric oxide combines with a portion of the protosulphate [223], so as to form a compound, that gives the dark tint to the water, in which it is dissolved—but which is so unstable that heat, or a slight agitation, causes it to disappear. Supposing the acid present, to be in combination with potash, $8(\text{SO}_3 + \text{FeO}) + 4\text{SO}_3 + (\text{NO}_5 + \text{KO}) = 3(3\text{SO}_3 + \text{Fe}_2\text{O}_3) + (\text{SO}_3 + \text{KO}) + 2(\text{SO}_3 + \text{FeO}) + \text{NO}_2$. Lastly, nitric acid gives a deep red colour with a crystal of morphia.

244. AMMONIA: *— *symb.* NH_3 ; *equiv.* 17·02. It is never found, in nature, in the free or uncombined form. What is present in the atmosphere, and is absorbed by rain, and snow water [213], is probably united with carbonic acid.—It is found to have the odour of perspiration, and night soil: which shows the principal sources, whence it is derived. The softness and peculiar feel of the hand, when moistened with rain water, is due to the presence of carbonate of ammonia.

245. Ammonia cannot be formed synthetically, except when the gases which constitute it are in the nascent state. If, however, as much nitric acid is added to zinc, placed in dilute sulphuric acid, as will cause the evolution of gas to cease, water and nitric acid will be decomposed, sulphate of zinc and sulphate of ammonia being produced. Iron may be used, instead of zinc. Ammonia may be obtained, by mixing in a mortar, equal weights of slaked lime (CaO) and sal-ammoniac (NH_4Cl), then placing the mixture in a retort, and gently heating it. Chloride of calcium, ammonia, and water, are the results. $\text{NH}_4\text{Cl} + \text{CaO} = \text{CaCl} + \text{NH}_3 + \text{HO}$. It must be collected over mercury: and should be transmitted to the receiver through a tube containing lime, or fused potash—to absorb any water which may be carried over with it.

246. Ammonia, so obtained, is a colourless gas; of a penetrating odour, and an acrid taste. It is neither a supporter of combustion, nor inflammable—though a small jet of it will burn in oxygen. It is irrespirable, causing, when inhaled along with common air, bronchitis or inflammation of the mucous membrane of the air passages of the lungs. Hence, applied in fainting fits, or to counteract the effects of prussic acid, &c., it must be used with caution: and instances are known, in which patients have died in such cases, from an over-dose of it. Its specific gravity is 0·59669:—100 cubic inches weigh 18·5044 grains. Water at 60°, absorbs more than 600 volumes of ammonia, with the evolu-

* So called, on account of one of its compounds being found near the temple of Jupiter Ammon, in Lybia.

tion of great heat: but if it is kept cold, it may be made to contain so much as 26.5 per cent. of that gas. Water holding it in solution is called "water of ammonia," or—incorrectly—"liquid ammonia." The apparatus, fig. 340, may be employed, in forming aqueous ammonia. Both that gas, and cyanogen, diminish the density of the water, with which they are combined:—hence the low specific gravity of their solutions is a proof of strength. Ammonia, associated with the elements of water, is an alkali: and from its volatility is termed the "volatile" alkali. It combines with the various acids, and hydracids, with sulphur, &c.—No base has a smaller atomic weight.

247. *Carbonate of ammonia* ($\text{CO}_2 + \text{NH}_4\text{O}$) may be obtained, by dissolving commercial sesquicarbonate of ammonia in four parts water, and adding one part strong water of ammonia. The solution of this salt should leave no residuum, on being evaporated.

248. *Nitrate of ammonia* ($\text{NO}_3 + \text{NH}_4\text{O}$) may be formed, by neutralizing water of ammonia, or saturating a solution of carbonate of ammonia with nitric acid. The salt [216] may be obtained by evaporation.

249. *Sulphite of ammonia* ($\text{SO}_2 + \text{NH}_4\text{O}$) may be made, by neutralizing water of ammonia with sulphurous acid.

250. *Sulphate of ammonia* ($\text{SO}_3 + \text{NH}_4\text{O}$) may be obtained, by neutralizing water of ammonia with sulphuric acid.

251. *Oxalate of ammonia* ($\text{C}_2\text{O}_3 + \text{NH}_4\text{O}$) may be made, by neutralizing water of ammonia with oxalic acid. It does not decompose by keeping: and is therefore more convenient, as a re-agent, than oxalic acid.

252. *Sal-ammoniac* (NH_4Cl) is formed abundantly, from the carbonate and sulphate of ammonia, contained in soot. The former is previously changed to a sulphate, by the addition of sulphate of lime: and the carbonate of lime, which results, is left behind, when the sulphate is removed, in solution. The sulphate of ammonia being evaporated to dryness, is mixed with common salt:—after which the sal-ammoniac, and sulphate of soda, produced, are separated by subliming the former. Sal-ammoniac is procured, also, by the decomposition of horns, bones, and other substances, containing nitrogen. It may be obtained, as a re-agent, by purifying the sal-ammoniac of commerce, with two or three recrystallizations.

253. *Hydrosulphuret of ammonia* ($\text{NH}_4\text{S} + \text{HS}$) may be made, by saturating a strong solution of ammonia with sulphuretted hydrogen, until the liquid ceases to give a precipitate with sulphate of magnesia. It is a colourless volatile liquid, and contains, at first, an excess of sulphuretted hydrogen; but on exposure to the air, it acquires a yellowish tinge; by the formation of a penta-sulphuret of ammonium (NH_4S_5), which will cause it, when mixed with acids, to deposit sulphur. Hydrosulphuret of ammonia, containing an excess of sulphur—obtained,

sometimes, by adding finely levigated sulphur—is frequently employed in testing. It may be known to have an excess, when it is of a yellowish colour.

254. Bichloride of platinum gives with ammonia a yellow crystalline precipitate ($\text{NH}_4\text{Cl} + \text{PtCl}_2$): and tartaric acid, in concentrated solutions, a crystalline bitartrate. An ammoniacal salt is detected with great certainty, by adding to the substance supposed to contain it, lime, or potash, and applying heat:—the ammonia which escapes will be perceived by its odour, and will restore the blue colour of reddened litmus paper, held over it.

255. There is some reason to believe that ammonia, like the other alkalis, is the oxide of a metal—which has been termed *ammonium*, its symbol being NH_4 . In such a case, what is ordinarily considered ammonia and water, will be oxide of ammonium:— $\text{NH}_3 + \text{HO} = \text{NH}_4 + \text{O}$. Ammonia forms with mercury under the action of the galvanic battery [183] an amalgam: but it is immediately re-produced, water being decomposed. This amalgam may be made, also, by dropping a grain of potassium, dissolved in 100 grains of mercury, into a strong solution of sal-ammoniac. The mercury swells up, and the resulting amalgam is sufficiently permanent, to be examined.

256. Some chemists have supposed that the proximate elements of ammonia are a substance, termed *amidogene* (NH_2) and hydrogen. For, potassium, in dry gaseous ammonia, liberates hydrogen: and amidide of potassium, an olive-coloured body, remains behind. The third atom of hydrogen, therefore, is not so strongly combined, as the others. It is likely that, in some cases—as for instance, with certain metallic compounds, and organic acids—ammonia acts as amidide of hydrogen, and abandons an atom of hydrogen. Thus, with protochloride of mercury (HgCl), it forms amidide of mercury, and hydrochloric acid. $\text{NH}_3 + \text{HgCl} = \text{HgNH}_2 + \text{HCl}$. Oxalate of ammonia ($\text{C}_2\text{O}_3 + \text{NH O}$) when heated, forms oxamide ($\text{C}_2\text{O}_2 + \text{NH}_2$) and two atoms of water. But it is probable that, in other cases, the amidide of hydrogen is associated with the elements of water, and acts as an alkali—forming an oxide of the metal ammonium.

It is supposed, that hydrogen combines, in three proportions, with nitrogen.

257. TER-CHLORIDE OF AZOTE:—*symb.* N.Cl_3 ; *equiv.* 120·43. It is obtained, by decomposing ammonia, with chlorine. Ter-chloride of azote, and hydrochloric acid, are the results. $\text{NH}_3 + \text{Cl}_2 = \text{NCl}_3 + 3\text{HCl}$. It is a very dangerous substance; since its elements have so feeble an affinity, that they are separated, by the least motion—a violent explosion being produced. Dulong, who discovered it, lost an eye and arm, during his experiments upon it.

258. Nitrogen forms, with iodine, likewise, an explosive com-

pound—not quite so violent, however, in its effects, as the terchloride: and, also, an analogous combination, with bromine.

259. CARBON:—*symb.* C.; *equiv.* 6. It is a very well known element; and constitutes, with small quantities of other bodies, coke and charcoal—the former being obtained, by igniting mineral coal, and the latter, wood, to a greater or less extent out of contact with the atmosphere. Coke, though apparently very soft, consists of crystalline plates so hard as actually to *cut* glass—any substance that is harder will *scratch* it. Great quantities of coke are manufactured from the refuse coal, of which about one million of tons was formerly burned each year at the mouth of the pit. Coal, in coking, loses one-fourth of its weight, but gains one-fourth in bulk. Wood, during the process of conversion into charcoal, loses about seventy-eight per cent. in weight. Theoretically, it should lose considerably less: but much of the carbon is necessarily carried off in combination with hydrogen: and much is wasted, by even the best methods of charring. Black lead—called also *plumbago*, and *graphite*—is a compound of carbon and iron: and, sometimes, consists of carbon alone. Karsten's experiments leave no doubt that it is a peculiar form of carbon; and that the foreign substances, it contains, are merely accidental. It may be procured, artificially, by adding an excess of carbon, to iron in a state of fusion, and allowing it to cool:—some of the carbon which it dissolved when hot, will separate in the crystalline form. Lamp black is almost entirely carbon. Ivory-black or animal charcoal contains the salts of the bones, which are burned to produce it. When these are heated in a close vessel, their gelatine is decomposed, carbonic acid, ammonia, and a fetid oil (Dippel's animal oil) being given off, and animal charcoal being left behind. Pure carbon may be obtained from this, by digesting it with dilute nitric acid, then washing it with water, and drying it at a proper heat. The diamond is carbon in a state of purity: and, as well as graphite, will burn in oxygen.

260. Carbon is a bad conductor of heat; but it transmits electricity freely. If oxygen is excluded, it is indestructible in the most intense fire. It absorbs gases in large quantities:—in making experiments, on this subject, the charcoal is to be strongly heated, and then cooled without access of air. A cubic inch of box-wood charcoal, which acts the best, was found to absorb of—

	Cubic inches.		Cubic inches.
Hydrogen,	1.75	Nitrous oxide,	40.00
Nitrogen, .	7.50	Sulphuretted hydrogen,	55.00
Oxygen, .	9.25	Sulphurous acid,	65.00
Carbonic acid, .	35.00	Hydrochloric acid,	85.00
Olefiant gas, .	35.00	Ammonia,	90.00

Charcoal exposed to the air becomes less inflammable, but gains in heating power. The cause of this is not known.

261. Tainted flesh, or bad water, may be purified with charcoal:—casks are charred inside, on account of this property. Its antiseptic qualities were known very early:—piles, driven down, for the foundations of bridges, more than 2,000 years ago, are found charred. Animal charcoal, boiled with ale, beer, port wine, &c., will render them colourless:—ordinary charcoal would not produce the same effect. When ale is decolourized by filtration through animal charcoal, the bitter principle also is removed: which prevents its being applied to the purpose.

262. Carbon forms, with oxygen, carbonic oxide (CO : 14); carbonic acid (CO_2 : 22), and oxalic acid (C_2O_3 : 36). With hydrogen, olefiant gas (C_2H_2 : 14); light carburetted hydrogen (CH_4 : 8): and a variety of compounds, the most important of which will be noticed at the proper times. It combines, also, with many of the other elements.

263. CARBONIC OXIDE:—*symp.* CO ; *equiv.* 14. It is procured, by mixing pounded chalk, limestone, or marble ($\text{CO}_2 + \text{CaO}$), with iron filings, and applying a strong heat. Half the oxygen goes to the iron; lime, oxide of iron, and carbonic oxide, being the results. $(\text{CO}_2 + \text{CaO}) + \text{Fe} = \text{CaO} + \text{FeO} + \text{CO}$. Charcoal would answer, in place of the iron: there would then be two atoms of carbonic oxide, and one of lime. $(\text{CO}_2 + \text{CaO}) + \text{C} = \text{CaO} + 2\text{CO}$. It may be obtained, likewise, by digesting either binxolate of potash $[(\text{C}_2\text{O}_3 + \text{KO}) + (\text{C}_2\text{O}_3 + \text{HO})]$, or oxalic acid ($\text{C}_2\text{O}_3 + \text{HO}$), with strong sulphuric acid. In the former case, the sulphuric acid, taking both the potash and basic water, liberates the oxalic acid, which, not being able to exist uncombined, is immediately decomposed into a mixture of carbonic acid and carbonic oxide, bisulphate of potash being formed. $[(\text{C}_2\text{O}_3 + \text{KO}) + \text{C}_2\text{O}_3 + \text{HO}] + 2\text{SO}_3 = [(\text{SO}_3 + \text{KO}) + (\text{SO}_3 + \text{HO})] + 2\text{CO}_2 + 2\text{CO}$. In the latter, the same mixed gas is liberated, by the oxalic acid being deprived of its basic water. $(\text{C}_2\text{O}_3 + \text{HO}) + \text{SO}_3 = (\text{SO}_3 + \text{HO}) + \text{CO}_2 + \text{CO}$. If the mixed gas is transmitted, from the retort, to a vessel containing a solution of caustic potash, the carbonic acid will be absorbed, carbonate of potash being formed: and pure carbonic oxide will pass out of the apparatus.

264. Carbonic oxide is without colour, taste, or smell; it burns with a bluish flame—which [162] might be expected, as the affinity which makes it combine with an atom of oxygen, to form carbonic acid, is not very strong. It supports neither combustion, nor respiration—producing narcotic effects. Its specific gravity is 0.9727:—100 cubic inches weigh 30.1651 grains.

265. Carbonic oxide is often produced in furnaces, instead of carbonic acid, from an insufficient supply of atmospheric air. It is not detected as it escapes; but the waste of fuel may

nevertheless be very great.—It is formed by decomposition of carbonic acid, as it passes over the red hot coals, an additional quantity of carbon being dissolved. In such a case the fuel gives considerably less heat than should be expected from it. The carbonic acid is never all decomposed.

266. CARBONIC ACID:—*ymb.* CO_2 ; *equiv.* 22. It was known long before its real nature was discovered—being considered by the ancients as a pestilential vapour, and termed by them “*spiritus lethalis*.”* Some of the more eminent alchymists believed it to be a particular body, and called it “*spiritus sylvestris*.”† Boerhave thought it was a form of atmospheric air. Black proved, in 1757, that it was a distinct substance, and obtained it:—he called it “fixed air,”‡ a name given to it before the experiments of Cavendish, and others, showed that it was an acid. Lavoisier accurately determined its composition—and it then obtained the names of “mephitic”§ and “aerial acid,” the “acid of charcoal,” and finally carbonic acid. The discovery of the true constitution of this gas, forms a most important era in chemistry. Before the researches of Black, the action of lime on the alkaline carbonates, which, as we shall find, is now so evident, was totally misunderstood. The lime was supposed, during the process of burning, to take from the fire, some element which rendered it caustic: || and which, being imparted to what are now known to be carbonates of the alkalies, transferred the causticity to them.—In his early experiments, Black endeavoured to obtain what was thus supposed to pass from the fire to the lime, and from the lime to the potash, &c.

267. Carbonic acid is found, most abundantly, in nature. It constitutes a large part, by weight, of limestone, marble, chalk, &c.: and is the chief product of combustion, and respiration. It may be procured from any of the carbonates, by acting on them with an acid. When carbonate of lime—marble, for example, which is nearly pure carbonate—is employed, it is better to use hydrochloric acid which forms a soluble, than sulphuric which forms an insoluble compound. With carbonate of lime and sulphuric acid, the results are carbonic acid and sulphate of lime. $(\text{CO}_2 + \text{CaO}) + \text{SO}_3 = (\text{SO}_3 + \text{CaO}) + \text{CO}_2$. When hydrochloric acid is used, chloride of calcium, carbonic acid and water are produced. $(\text{CO}_2 + \text{CaO}) + \text{HCl} = \text{ClCa} + \text{CO}_2 + \text{HO}$.

268. Carbonic acid is a colourless gas; it has a rather sharp taste, and a very pungent smell. It is neither a combustible, nor a supporter of combustion or respiration. If the nose is

* A deadly air. *Lat.*

† Forest air. *Lat.*

‡ It was termed *fixed* or *fixable* air, from being found “fixed” in limestone, &c. This name had been given to other gases, which were found to be contained in solids, &c.

§ *Mephitis*, an ill odour. *Lat.*

|| *Kauo*, I burn. *Gr.*

held incautiously over a vessel from which it is escaping, it may cause coughing, and sneezing—and even giddiness, and weakness. The glottis closes, spasmodically, against it. It is the “choke-damp” of the miners: but if taken into the lungs diluted with common air, it is narcotic. Persons are frequently suffocated by it, in breweries, distilleries, lime-kilns, &c.; also, those who sleep in rooms without chimneys, while fire is burning. A grotto, near Naples, is called the “Grotto del cane,”* from the effect it produces on these animals.—It contains a spring of carbonic acid, which rises to the height of about twelve inches, and then flows over the entrance, into the lake below. A human being experiences no inconvenience within it, since his head is far above the level of the gas. Throwing the dog, which has been affected by the carbonic acid, into the lake, recovers it—provided the remedy is applied sufficiently soon. Generally speaking, there is no danger from carbonic acid, where a candle will burn. This, however, is not always true; and it would be infatuation to venture, where a candle is extinguished. It is not merely the want of oxygen, which causes the candle to go out: the carbonic acid exercises a positive influence, since it will not burn in an atmosphere containing one-fifth of its volume of this gas. Water absorbs, under the ordinary atmospheric pressure, an equal volume of it—which is given out again by boiling, or reducing the pressure. Its presence in water, causes that fluid to sparkle, when poured from one glass to another; and the want of it, in recently boiled water, makes the latter insipid. Under increased pressure, water absorbs still larger quantities—dependent on the pressure. Though poisonous, when taken into the lungs, it is harmless, or even advantageous, as a sedative, when taken into the stomach, in moderate quantities.—Soda-water is nothing more than common water, into which carbonic acid has been forced, under great pressure, and which contains, also, a small quantity of potash, soda, &c. The acid properties of this gas may be proved, by its reddening litmus paper: the colour of which, however, returns, when the acid volatilizes. Its specific gravity is 1.511:—100 cubic inches weigh 46.8587 grains. That it is much heavier than common air, may be very strikingly illustrated, by pouring it from one glass jar into another, containing atmospheric air, and then over a candle—which it will immediately extinguish. The spectator sees nothing pass from one jar to the other; and yet the air within the latter has put out the candle—though what it contained, at first, would not produce that effect.

269. Carbonic acid, at a temperature of 0° , is liquefied by a pressure of thirty-six atmospheres; and when the pressure is

* “Dogs’ grotto.” *Ital.*

suddenly removed congeals by the cold arising from its own evaporation. Liquid carbonic acid is a limpid and colourless fluid. Its specific gravity at 32° is 0.83. It distils rapidly, at a temperature between 0° and 32° . It is insoluble in water or the fat oils: but dissolves readily in alcohol, ether, turpentine, &c. Solid carbonic acid resembles asbestos. Being a bad conductor of heat, it does not evaporate rapidly, nor feel very cold. It dissolves in alcohol, and ether. The evaporation of its ethereal solution, produces the lowest temperature, known [heat 118]. Faraday availed himself of the cold obtained by it—in conjunction with great pressure—to liquefy, and even solidify, several of the gases.

270. Carbonic acid is a powerful agent, in the disintegration of rocks. Even water containing it corrodes them: since [195] it dissolves carbonate of lime. In this way, *stalactites* and *stalagmites* are formed, in limestone caverns.—The rain water, holding carbonic acid in solution, trickles down through their roofs, and dissolves the carbonate, in its passage: and, as it hangs in drops, the carbonic acid passes off, leaving carbonate of lime in the solid state—which produces those beautiful, and often fantastic pendants, called “stalactites.” When the water drops on the floor of the cave, the carbonate of lime, precipitated in the same way, forms “stalagmites.” The trickling of rain water, through the arches of bridges, vaults, &c., gives rise to similar effects, but generally on a small scale. Carbonic acid dissolves carbonate of lead ($\text{CO}_2 + \text{PbO}$)—which, sometimes causes water, contained in leaden cisterns, or passing through leaden pipes, to possess very deleterious qualities. Carbonate of lead is, in these cases, formed by some of the oxygen, and carbonic acid, contained in the water, and is dissolved by another portion of the acid:—the lead would be protected by minute quantities of the salts, generally found in natural water. Hence the cisterns, &c., which are used for rain, or any almost pure water, and the covers of others, that are moistened by what has evaporated—and has, therefore, left behind, the solid substances, it originally held in solution—are most affected in this way. It may be proved, that the atmosphere contains carbonic acid, by passing a quantity of common air, through lime-water. Carbonate of lime ($\text{CO}_2 + \text{CaO}$), will be, at first, precipitated, and will, afterwards, be redissolved, by excess of the acid.

271. Gay Lussac, has shown, that plants decompose some of the carbonic acid of the atmosphere, since, in France, there are large forests, in siliceous soils which contain no organic matter:—their entire carbon, must, therefore, be derived from the atmosphere. We shall find, that plants absorb carbonic acid, during the day: and decompose some of it, oxygen being evolved—

particularly in sunshine. Thus the injury done to the atmosphere, by the animal, is repaired by the vegetable kingdom. Carbonic acid is evolved by living plants, at night: and by those in a state of decomposition, at all times.

Oxalic acid will be examined, among the vegetable acids.

272. OLEFIANT* GAS :—*ymb.* C_2H_2 ; *equiv.* 14. It is so called, because, with chlorine, it forms a fluid resembling oil in appearance: and is obtained, by mixing in a large retort, one part, by weight, of very strong alcohol, with four parts oil of vitriol, and applying heat.—An equal weight of the oil of vitriol, would produce sulphuric ether.

273. Olefiant gas has neither colour, taste, nor smell. It is inflammable; but does not support combustion, nor respiration. Its specific gravity is 0.9746:—100 cubic inches weigh 30.224 grains. It is highly important, on account of being the most valuable constituent of gases used for illumination. It is also very interesting from being, most probably, the *radical* of a great number of substances, to which I shall advert, hereafter.

274. LIGHT CARBURETTED HYDROGEN, OR MARSH GAS:—*ymb.* CH_4 ; *equiv.* 8. It can be obtained—along with carbonic acid, however—by stirring up stagnant pools. It is evolved, also, by heating well mixed equal parts of acetate of potash ($C_4H_3O_3 + KO$), and caustic potash. Water is decomposed, carbonic acid, and light carburetted hydrogen being given off. The carbonic acid unites with the potash, and the light carburetted hydrogen may be collected, over water. $(C_4H_3O_3 + KO) + KO + HO = 2(CO_2 + KO) + 2CH_4$.

275. This gas has neither colour, taste, nor smell. It is highly inflammable—water and carbonic acid being the result of its combustion; it is a component of all the gases, used for illumination. It does not support either combustion, or respiration. Its specific gravity is 0.557:—100 cubic inches weigh 17.2735 grains. It forms a highly explosive mixture, with common air: and is termed “the fire damp,” by miners. It is evolved, abundantly, in coal mines: and is produced, whenever vegetable matter is decomposed, under water. The lignine ($C_{12}H_8O_8$)—or woody fibre, forms, with four atoms of water, six atoms of carbonic acid, and six atoms of this gas. $C_{12}H_8O_8 + 4HO = 6CO_2 + 6CH_4$. Coal being the remains of enormous accumulations of wood, large quantities of marsh gas were evolved by it, and were liquefied, by the immense pressure;—but, when the latter is removed, it assumes the gaseous form, and escapes into the mine. Davy’s lamp [187] prevents the danger, arising from its mixture with common air.

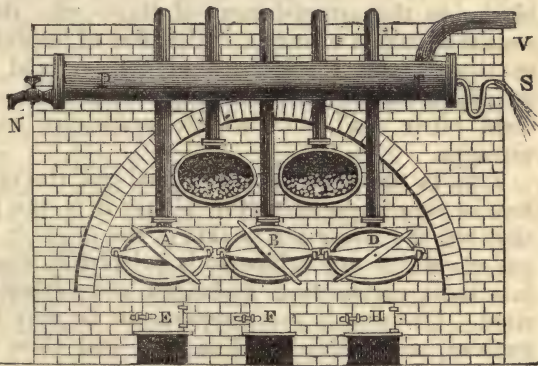
276. GASES FOR ILLUMINATION.—COAL GAS. Dr. Clayton ob-

* *Oleum*, oil; and *fio*, I am made. *Lat.*

served, in the year 1664, that combustible illuminating gas was produced, during the decomposition of coal by heat. Lord Dundonald, to amuse himself, built some coke furnaces in 1786, collected the gas, and burned it in tubes. The factory of Bolton and Watt was lighted with gas in 1798. London was first lighted with it in 1812: and Paris in 1815. The Chinese, though they did not manufacture this gas, employed it for the purpose of lighting, and heating, long before it was thus used by Europeans.—Their salt borers frequently pierce beds of coal, and convey the inflammable gas, in pipes, to the salt works, to light them, and to evaporate the salt, &c.;—when there is more gas than is necessary, they burn it outside the works, in their streets, &c.

277. Coal gas is obtained from bituminous coal:—and the apparatus used, though varied, in its details, according to circumstances, is always the same, in principle. In the production of gas for the illumination of cities, the works are of immense extent, and the quantity produced is very great. The coal is

FIG. 341.



placed in cast iron retorts A, B, D, &c., fig. 341, and heated to a cherry red. If the retorts are at first cold, the tar—which is the chief product, at a temperature below redness—is merely volatilized: but little gas, which is almost entirely hydrogen and atmospheric air, being obtained. Heat decomposes the tar. Towards the end of the process, if it is continued beyond a certain time, almost pure hydrogen is evolved: the hydrocarbons being decomposed in passing over the intensely hot coke, &c. Iron retorts are rapidly destroyed by the action of the atmospheric air, at a high temperature, by the sulphur present in the coal, and by the carbon—which, combining with the iron, forms graphite. Hence those which are now very commonly employed are made of earthenware.

278. Coal gas is a complicated compound. It contains ammonia [244], cyanogen (C_2N or Cy.), sulpho-cyanogen ($Cy S_2$) sulphur, sulphurous acid (SO_2), carbonic oxide [263], carbonic acid [266], hydrochloric acid (HCl), olefiant gas [272], light

carburetted hydrogen [274], etherine (C_4H_4), bicarburetted hydrogen (C_2H), sulphuretted hydrogen (SH), bisulphuret of carbon (CS_2), water, and very frequently hydrogen. Naphthaline (H_4C_{10}) and naptha (H_5C_6) are present, in the form of vapour: and give to coal gas its peculiar smell. The carbonic oxide, and hydrogen, are due to the decomposition of the vapour of water, as it passes over the ignited coke. The nitrogen of the coal, assumes the form of cyanogen, and ammonia:—any, in the free state, is the residue of atmospheric air, which was in the retort, when the coal was introduced. Coal contains the one-five-thousandth of its weight of ammonia; and coal gas, the one-three-hundredth of its volume. Some of the ammonia, is in combination with sulpho-cyanogen, &c. The sulphuretted hydrogen, and sulphurous acid, are derived from iron pyrites (FeS_2), in the coal. The former gives but little light, and during combustion, forms sulphurous acid, and water. The smoke from a coal fire has, from containing it, sometimes produced an inconvenient effect, on persons using a salt of bismuth as a cosmetic: having been known to render the face almost black, to the astonishment of those who did not know the reason of such a change.—Sulphuret of bismuth, was produced, in these cases. Sulphuret of carbon, and sulpho-cyanogen would, in burning, produce sulphurous acid. Ammonia, would form nitric acid, and water: cyanogen, carbonic acid, and nitrogen.

279. In the manufacture of coal gas, the management of the heat is very important; the higher it is, the greater the quantity, but the worse the quality of the product. For, the olefiant gas, to which its brilliancy is principally due, is decomposed into light carburetted hydrogen, and carbon—which is deposited. Or even, if the temperature be very high, hydrogen is evolved, uncombined with carbon: and then, the gas obtained, gives great heat, and but little light [190].—The higher the specific gravity of coal gas, the larger the quantity of carbon it contains, and the greater its illuminating power.

280. The manufacture of coke, for smelting purposes, locomotives, &c., requires conditions incompatible with the economical production of illuminating gases [steam 91]. Hence in manufacturing it on the large scale, they are allowed to be consumed, to escape, or to contribute by their combustion to the production of the coke. The object of the manufacturer is, to obtain the coke as dense, and in as large masses as possible. This cannot be effected with large coal [259]—which must therefore, when employed, even be broken up artificially. The best coke is obtained from large masses of coal: and ten or fifteen tons are sometimes placed in a single oven.—A gas retort would be charged with about one and a half cwt. The air

is allowed, with certain precautions, to have access to the coal during the process of coking. Both the amount and density are improved, by the deposition of carbon from the decomposed hydrocarbons:—this, however [279], deteriorates the quality of the gas. In the best methods of manufacture, after the process is completed, air is excluded from the coke: which being kept for some time in the heated state, contracts in bulk and increases in density.

281. The coal gas is first passed through tar, in the pipe PT, fig. 341: which causes tar, and bitumen, to be condensed, and deposited. It is then cooled, by transmission through pipes surrounded with water; and is next passed through cream of lime—a mixture of lime and water, kept agitated by machinery—which removes the carbonic acid, by forming carbonate of lime ($\text{CO}_2 + \text{CaO}$), and the sulphuretted hydrogen, by forming sulphuret of calcium (CaS), and [254] decomposes the ammoniacal salts, the ammonia being absorbed by the water.

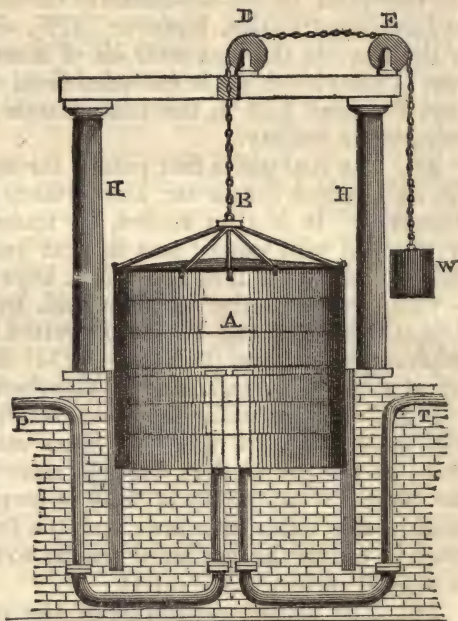
282. Trellis work—or sieves—covered with moss, well mixed with moist lime, are now very often used instead of cream of lime; as the gas is, thus, brought more fully into contact with the lime. When cream of lime is employed, there is, also, a considerable water pressure; and the force, necessary to overcome it, causes the gas more readily to leak, and more rapidly to deposit carbon in the retort.

283. The perfect separation of the ammonia is a matter of equal difficulty, and importance. If it is removed by an acid, unless certain precautions are used, the illuminating power is impaired. Transmitting the gas, before it arrives at the lime, through a weak solution of sulphuric acid, which is gradually increased in quantity as it combines with the ammonia, is found to answer extremely well. Eighty ounces of sulphate of ammonia, are then obtained, for every gallon of the fluid; while the ordinary ammoniacal liquor, affords only 14 ounces. Besides saving the cocks, &c., the separation of all the ammonia is said to increase the illuminating power, five per cent. Naphthaline, though it increases the brilliancy of the gas, is injurious, on account of forming crystalline deposits, in the tubes. Various other contrivances are used, for removing impurities. The amount of gas produced, varies with the kind of coal.—100 cubic feet of the latter, give about 19,000 cubic feet of the former.

284. When the gas is purified, it is transmitted to a *gas-holder* or reservoir—improperly called a *gasometer*. It consists of a cylindrical vessel A, fig. 342, made of wrought-iron plates, riveted together, so as to be air-tight. The open end is immersed in an annular cavity, filled with water, which—to prevent evaporation—is covered with a layer of tar. A, is so balanced, by a weight W, that it is easily raised by the gas.

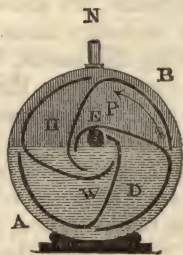
The latter enters by the pipe P, and is brought to the mains, by the pipe T—the pressure which forces it out, being regulated by the amount of the counterpoise W. It is conveyed from the mains by iron, leaden, &c., tubes.—It has been found that, when copper is used for the purpose, a pulverulent substance, liable to spontaneous combustion, is formed by combination of the metal with the elements of the gas.

FIG. 342.



285. The quantity of gas, consumed by individuals, &c., is now, very generally, registered, by a *gas meter*—the principle of which may be understood, from fig. 343. The gas enters by a pipe, under E, and, by its buoyancy, causes the partitions—indicated by thick lines, and forming separate chambers of known capacity—to revolve on an axis. As each chamber is filled, it moves round, and communicates with that portion of the drum, which is above the water. The gas is conveyed by the pipe N, to the burners. The axle, in revolving, communicates motion to a train of wheels and pinions having, externally, dials and indices, which mark, respectively, hundreds, thousands, &c., of cubic feet. Each pinion moves a wheel, having ten times as many teeth as it has leaves.—Ten revolutions therefore, of one wheel [mech. 198], correspond with one of the next. Neither the gas company, nor the consumer, can alter the indication—which must be accurate, if the proper water level is maintained. There are other kinds of gas meter: some of them requiring no water.

FIG. 343.



286. Since the illuminating power of a gas, depends on the quantity of carbon united with the hydrogen, various plans

have been devised, to saturate inferior gas with naphtha—a substance extremely rich in carbon, and one of the products obtained by the destructive distillation of coal. This is effected, by passing the gas through the naphtha; or, otherwise bringing the two substances into contact. Naphthalized gas has the advantage of evolving less heat, during combustion: the quantity which it gives out, the illuminating power remaining the same, being to that evolved by ordinary coal gas, as three is to four; and the light, which results, more closely resembles that of the sun.

287. OIL GAS is obtained, by dropping fish oil, and substances not fit for lamps, &c., on iron, coke, or bricks, raised to a high temperature. It gives twice as much light as coal gas: having a larger quantity of olefant gas—and no sulphuretted hydrogen. It does not require to be purified with lime. One cubic foot of oil produces, from six to seven hundred cubic feet of gas: which is equivalent to, from 90, to 96 per cent., by weight. Oil gas has nearly the same density as atmospheric air.

288. When resin is used for the production of gas, it is necessary to render it fluid, before submitting it to destructive distillation. For this purpose, oil of tar, &c., are employed. From 14 to 23 cubic feet of gas, are obtained, by the destructive distillation of one pound of resin.

289. To obviate the necessity of using pipes, and other expensive apparatus, ordinarily required, various plans have been proposed, for the application of *portable* gas to the purposes of illumination. The first means devised, was the compression of a considerable quantity, into a small but strong receiver, attached to and forming a part of the lamp, &c. This method, however, is attended with several disadvantages. Vessels of great strength are necessary, on account of the force of compressed gas—often considerably increased by unavoidable changes of temperature. Moreover, the carbo-hydrogens, contained in illuminating gases, have their illuminating power greatly diminished, by compression: since, a liquid containing a valuable part of the constituents of oil gas—which is the most proper for the purpose—and consisting of three different substances, triyle (C_3H_3), ditriyle (C_2H_4), and another hydrocarbon (C_2H_3), separates. The danger of explosion, and the difficulty of obtaining a uniform flow of gas with the constantly diminishing pressure, are other inconveniences.

Portable uncompressed gas, has also been tried; but, has not been much used.

CHAPTER III.

Sulphur, 290.—Hyposulphurous Acid, 293.—Sulphurous Acid, 294.—Sulphuric Acid, 298.—Sulphuretted Hydrogen, 311.—Selenium, 316.—Phosphorus, 319.—Phosphuretted Hydrogen, 325.—Chlorine, 328.—Hypochlorous Acid; Bleaching Salts, &c., 339.—Chlorous Acid, 345.—Perchlorous Acid, 346.—Chloric Acid, 348.—Hydrochloric Acid, 351.—Aqua Regia, 358.—Iodine, 359.—Bromine, 364.—Fluorine, 368.—Hydrofluoric Acid, 370.—Silicon, 373.—Silex, 376.—Manufacture of Porcelain, 380.—Manufacture of Glass, 387.—Soluble Glass, 411.—Fluoride of Silicon, 416.—Boron, 421.

290. SULPHUR:—*symb.* S; *equiv.* 16. It is found, principally, in the neighbourhood of volcanos; and is obtained, also, in large quantities, combined with metals, &c. The best sulphur, is brought from Sicily. Its chief properties are well known:—it is a non-conductor of heat, and of electricity; it melts at 226° , takes fire at 300° , begins to be thick, and of a reddish colour, at 320° , becomes somewhat liquid, again, at 482° , and is completely so, at 601° : it then sublimes, and forms “flowers” of sulphur. If, at a temperature of 400° , it is suddenly immersed in cold water, it forms a soft transparent elastic mass; but it gradually changes to its ordinary state. It may be shown that sulphur crystallizes when cooling, by melting a tolerably large quantity, breaking the crust on its surface before the mass is quite cold, and pouring out the part which is still liquid:—the internal portion will then present a crystalline appearance. Its specific gravity is 1.98. It dissolves in the oils; also, in caustic potash, cream of lime, &c., producing new compounds.

291. Sulphur forms, with oxygen, hyposulphurous acid (S_2O_2 ; 48); sulphurous acid (SO_2 ; 32); a group consisting of hyposulphuric or—as it has been termed by Sir R. Kane—deuto-thionic acid (S_2O_5 ; 72), trito-thionic acid (S_3O_5 ; 88), tetra-thionic acid (S_4O_5 ; 104), penta-thionic acid (S_5O_5 ; 120); also sulphuric acid (SO_3 ; 40); and two other compounds, not, as yet, well known. It forms, with hydrogen, sulphuretted hydrogen (HS ; 17); and bisulphuretted hydrogen (HS_2 ; 33). It combines, likewise, with carbon, &c.

292. The compounds of sulphur, very much resemble those of oxygen: for the sulphurets are extremely like oxides; and sulphur forms sulphur-salts, as oxygen forms oxy-salts—being, at the same time, the acidifying principle, and the element which, in the base of an oxy-salt, holds the place of oxygen.

Thus, sulphur and arsenic form *sulpharsenious* acid: which, combining with the sulphuret of lead, forms sulpharsenite of lead.

The resemblance is very clearly illustrated by the following—

Sulphocarbonic acid is	CS_2
Carbonic acid	CO_2
Sulphocarbonate of potassium	$\text{CS}_2 + \text{KS}$.
Carbonate of potash	$\text{CO}_2 + \text{KO}$.
Sulpharsenic acid	AsS_3 .
Arsenic acid	AsO_3 .
Sulpharsenate of potash	$\text{AsS}_3 + \text{KS}$.
Arsenate of potash	$\text{AsO}_3 + \text{KO}$.

293. **HYPOSULPHUROUS ACID**:—*ymb.* S_2O_2 ; *equiv.* 48. It is interesting, chiefly on account of hyposulphite of soda ($\text{S}_2\text{O}_2 + \text{NaO}$), one of its compounds, being used in the daguerreotype process [opt. 137]. It may be obtained, by adding to one of its salts a stronger acid. Or—which is more convenient—bringing sulphurous acid (SO_2) and sulphuretted hydrogen (SH) into contact, under water. $4\text{SO}_2 + 2\text{SH} = 3\text{S}_2\text{O}_2 + 2\text{HO}$. The water becomes exceedingly sour; but, after a while, the acid is decomposed, sulphurous acid being formed, and sulphur precipitated.

294. **SULPHUROUS ACID**:—*ymb.* SO_2 ; *equiv.* 32. It is formed, when sulphur is burned in atmospheric air, or in dry oxygen; also, when sulphuric acid (SO_3) is deprived of an atom of its oxygen, by being boiled with a metal. It is very conveniently procured, by heating together chips of wood and sulphuric acid.

295. Sulphurous acid is a colourless gas, having a very pungent odour. Its specific gravity is 2.21:—100 cubic inches weigh 68.5359 grains. At 0° Fahrenheit, it is a liquid, which is heavier than water, and boils at 14° . It is neither inflammable, nor a supporter of combustion:—and has a very suffocating effect, when breathed. It destroys vegetable colours: sometimes first reddening them. But the colour gradually returns, on account of the escape of the sulphurous acid, from the colourless compounds it had formed with the colouring matter: and it may be restored, at once, by the action of an alkali, or of a stronger acid—sulphurous acid being given off. Its power of removing vegetable colours may be illustrated, by placing a red rose in the fumes of burning sulphur; the colour will vanish, but will be brought back, by washing in dilute sulphuric acid. Water absorbs 37 volumes of sulphurous acid: and has, then, to a very high degree, the properties of the gas. The solution, if boiled, gives out the sulphurous acid; and, if kept, absorbs oxygen—sulphuric acid being formed. This gas is absorbed, still more abundantly, by alcohol. It is a very feeble acid: being displaced from its combinations by all others, except the carbonic, and hydrocyanic.

296. Many of the properties of sulphurous acid, are due to its affinity for oxygen. It stops fermentation, by absorbing that element:—hence, sulphur matches, are sometimes lighted over the bung-holes of casks, containing cider. It bleaches wool, or silk, by taking oxygen from the colouring matter; and is used, with these substances, instead of chlorine—which would be very injurious, if employed to decolourize them. It reduces gold, silver, or mercury, when in the form of salts. Thus, ter-chloride of gold (AuCl_3) sulphurous acid and water, produce sulphuric acid (SO_3), hydrochloric acid (HCl) and metallic gold. $\text{AuCl}_3 + 3\text{SO}_2 + 3\text{HO} = 3\text{SO}_3 + 3\text{HCl} + \text{Au}$.

Peroxide of iron (Fe_2O_3), in similar circumstances, gives only one-third of its oxygen to the sulphurous acid: and black oxide of copper (CuO), but one-half.

297. The salts of sulphurous acid, produce the same deoxidizing effects; and all of them, that are soluble, have an alkaline reaction.

298. SULPHURIC ACID:—*ymb.* SO_3 ; *equiv.* 40. It was discovered by Basil Valentine, an alchymist, about the end of the fifteenth century: and is found abundantly in nature—combined with lime, &c.

Absolute sulphuric acid—or that which contains no water, and is therefore termed “anhydrous”—could not be procured, until a comparatively recent period. It is obtained by expelling the acid from protosulphate of iron ($\text{SO}_3 + \text{FeO} + 7\text{HO}$), by a red heat. The crystals lose six atoms of their water, before the salt is decomposed: and the seventh, when decomposition commences. A red heat drives off the sulphuric acid, which, if the sulphate was quite dry, resolves itself spontaneously into sulphurous acid and oxygen: otherwise, sulphuric acid and water (probably $2\text{SO}_3 + \text{HO}$) distil over in combination as a thick, oily, dark coloured liquid, having a specific gravity of about 1.9. One-half of the sulphuric acid is, at the same time, decomposed, to peroxidate the iron, sulphurous acid being evolved. $4(\text{SO}_3 + \text{FeO}) + \text{HO} = (2\text{SO}_3 + \text{HO}) + 2\text{SO}_2 + 2\text{Fe}_2\text{O}_3$. This oily liquid is received in a vessel, cooled externally: and is the fuming sulphuric acid, known as “German oil of vitriol.”* When heated, it resolves itself into common oil of vitriol ($\text{SO}_3 + \text{HO}$), and absolute acid (SO_3). The latter being very volatile, distils over in colourless vapours: and, if received in a dry vessel, which is cooled by a freezing mixture, it condenses into tough, and elastic white silky fibres.

299. Solid absolute sulphuric acid, has a specific gravity of 27.66. It melts at 77° ; and boils at a temperature, but little higher. Thrown into water, it hisses like red hot iron. Its

* *Vitrum*, glass. *Lat.* The sulphates were formerly called “vitriols,” from their glassy appearance; and their acid was termed “vitriolic.” Strong vitriolic acid was called “oil” of vitriol, from its oily appearance.

combination with dry barytes, lime, or magnesia, is accompanied by brilliant combustion.

The absolute acid forms several compounds with water; and mixes with it, in all proportions.

300. *Aqueous sulphuric acid* is made, on the large scale, by mixing sulphur with one-eighth of its weight of nitre ($\text{NO}_3 + \text{KO}$), and burning them in a furnace: the fumes produced by the combustion, being transmitted, along with a current of atmospheric air, into a leaden chamber, the bottom of which is slightly inclined, and is covered with water. The oxygen of the atmosphere, forms sulphuric acid, with some of the sulphur. Another portion of the latter, combines with three atoms of oxygen, belonging to the nitric acid of the nitre: and the sulphuric acid so formed unites with the potash of the nitre, forming sulphate of potash. The residual nitric oxide is evolved, and is changed into hyponitrous acid [220], by the oxygen of the atmosphere. $(\text{NO}_3 + \text{KO}) + \text{S}_2 + \text{O}_3 = (\text{SO}_3 + \text{KO}) + \text{SO}_2 + \text{NO}_2$. The sulphurous, and hyponitrous acids, pass into the leaden chamber; and the sulphate of potash remains in the furnace. The mixed gases, in the presence of vapour of water—sometimes obtained from steam—and sulphuric acid, form nitro-sulphuric acid or sulphate of nitric oxide ($\text{SO}_3 + \text{NO}_2$, a white crystalline compound, which is capable of being distilled unchanged. This sulphate falling into the water, is decomposed into sulphuric acid, and nitric oxide. The former combines with the water: the latter ascends, and, by absorbing oxygen from the atmosphere, again becomes hyponitrous acid. If it were not necessary to expel the residual nitrogen of the atmosphere from the chamber, which causes some of the hyponitrous acid to be lost, the same nitric oxide would be sufficient to change any quantity of sulphurous into sulphuric acid.

Sulphurous and nitrous acids—particularly with the vapour of water—also form a crystalline solid ($\text{SO}_2 + \text{NO}_2$). It is decomposed by the larger quantity of water, into which it falls; and the hyponitrous acid disengaged from it forms nitric acid, which remains in solution, and nitric oxide, which with the oxygen of the air becomes again hyponitrous acid. $3\text{NO}_2 = \text{NO}_3 + 2\text{NO}$.

301. In the improved modes of manufacturing sulphuric acid, sulphur is burned in a furnace; and the resulting sulphurous acid is transmitted, along with fumes of nitric acid—evolved from nitrate of potash or soda, by means of sulphuric acid [229]—into the leaden chamber. Three atoms of oxygen, belonging to this nitric acid, combine directly with some of the sulphurous acid, changing three atoms of it, into sulphuric acid; the nitric oxide, derived from the decomposed acid, becoming, as in the former process, hyponitrous acid, forms sulphate of nitric oxide: and the latter, by falling into the

water, is resolved into sulphuric acid and nitric oxide, as before. When this process is employed, 1 lb. of sulphur will produce 3 lbs. of oil of vitriol ($\text{SO}_3 + \text{HO}$):—and only 3 lbs. nitrate of soda, are required for every 100 lbs. of sulphur.

302. The dilute sulphuric acid which, after some time, is formed in the leaden chamber, is deprived of a portion of its water, by boiling in leaden retorts. But, before it reaches the specific gravity of 1.750 it is removed into others, of glass, or platinum: since, at that temperature, it would act on the lead. When its specific gravity is 1.847, its boiling point being 617° , it would melt the lead, which fuses, at 594° .

303. The sulphuric acid of commerce is, generally, found to have certain impurities. If, on diluting it with water, it becomes turbid, it contains sulphate of lead—which is only sparingly soluble in the dilute acid. It contains, also, occasionally, small quantities of nitric acid, formed in the leaden chamber; and, sometimes, sulphate of nitric oxide [300]—which corrodes the lead, and platinum. It is purified, by redistillation: the nitric acid passes off with the first products; and the sulphates of lead, and of nitric oxide, will be left behind in the retort. It is better, however, to decompose the latter sulphate, previous to distillation, by adding one-half per cent. sulphate of ammonia ($\text{SO}_3 + \text{NH}_4\text{O}$):—the ammonia, and nitric oxide, will be changed into water, and nitrogen.

304. In distilling sulphuric acid, it will not be necessary to use a refrigerating apparatus [107]; since, as it exists in the vaporous form only at a high temperature, the atmosphere, alone, will condense it in the receiver. The sudden bursts of vapour, and the consequent fall of so heavy a liquid on the thin glass, renders it liable to break the retort in which it is distilled. This danger is, however, removed, by placing platinum wire or foil in the acid:—the angles cause the vapour to be gradually given off. Oersted and others have remarked that fluids, having in them wire or foil, boil at a lower temperature.

305. Oil of vitriol, the strongest aqueous sulphuric acid we can obtain by concentration—and which may be known by its giving off dense white fumes, during ebullition—contains but one atom of water; its specific gravity is 1.847; and it boils at 617° . When these fumes are perceived, the process of concentration may be stopped.

306. Strong sulphuric acid acts on very few metals, except at the boiling point. For, being an *ox*-acid [25], it combines, not with the metal itself, but with its oxide; and it has too strong an affinity for water, to allow that with which it is united, to be decomposed that the metal may take oxygen. The metal, therefore, must be already in a state of oxide; or it must be oxidized, by decomposition of water—which is added to the acid, for the purpose [180]. At the boiling point, the

acid itself suffers decomposition:—some of its oxygen combines with the metal, to form oxide; and sulphurous acid passes off. Below its boiling point, the sulphuric displaces all other acids from bases; but at a higher temperature, it is itself displaced, by certain weaker acids that are not volatile [130].

307. Sulphuric acid is very corrosive; it destroys, or changes animal and vegetable substances, on account of its affinity for water—which it forms, from a portion of their elements. When water is added to strong sulphuric acid, condensation occurs, and [35] great heat is evolved. Hence, the mixture must be made with caution; and, to prevent any danger of explosion, the acid should be poured into the middle of a vortex, formed by stirring the water rapidly round with a glass rod. Sulphuric acid, having a specific gravity of 1·780, contains two atoms of water, and forms crystals, at 32°. A stronger, or a weaker acid, requires a much lower temperature.

308. Dilute sulphuric acid decomposes the compounds formed by salts of lead and animal substances. Hence, it is sometimes used as a preventative against “painter’s colic.” A few drops of it, added to a tolerably large quantity of cold water, makes an agreeable drink.

309. The presence of sulphuric acid is detected, with great facility, by a salt of barytes—the nitrate ($\text{NO}_3 + \text{BaO}$) being generally used for the purpose. The affinity of sulphuric acid for barytes is so strong [133], that it will leave any substance, to combine with it, and form sulphate of barytes ($\text{SO}_3 + \text{BaO}$). The latter is a white precipitate: and is the only salt of barytes, which is insoluble.—It is not dissolved, even by nitric or hydrochloric acid at a boiling temperature. If the nitrate of barytes is—for example—added to a liquid containing sulphate of potash, sulphate of barytes will be thrown down, and nitrate of potash will remain in solution. $(\text{SO}_3 + \text{KO}) + (\text{NO}_3 + \text{BaO}) = (\text{SO}_3 + \text{BaO}) + (\text{NO}_3 + \text{KO})$.

The other combinations of sulphur, and oxygen, are not of sufficient importance to require notice.

310. It is supposed, that the compounds of sulphur and oxygen, are, in reality, combinations of sulphurous acid—as a radical [19]—with oxygen. This opinion is rendered more probable, by the fact that sulphurous acid, only, can be formed by the direct union of oxygen and sulphur. It greatly simplifies the constitution of substances consisting of sulphur and oxygen, &c.:—for then

Hypo-sulphurous acid would be	. $\text{SO}_2 + \text{S}$
Sulphuric acid,	. $\text{SO}_2 + \text{O}$
Chloro-sulphuric acid,	. $\text{SO}_2 + \text{Cl}$
Iodo-sulphurous acid,	. $\text{SO}_2 + \text{I}$
Nitro sulphurous acid,	. $\text{SO}_2 + \text{NO}$
Hyposulphuric, or deutothionic acid,	$2\text{SO}_2 + \text{O}$, &c.

311. SULPHURETTED HYDROGEN:—*ymb.* HS; *equiv.* 17. It is called also—and more correctly—“hydro-sulphuric acid,” being an hydracid [21]. It is disengaged, abundantly, from many animal, and vegetable substances, in a state of decomposition; and is formed, in the intestines of living animals. It is evolved, in large quantities, from the water of what are called “sulphurous” mineral springs—such as that at Harrogate, in England, and those of Golden-bridge, and Lucan, in Ireland—the gas being, most likely, due to water acting on native sulphurets within the earth, at a high temperature.

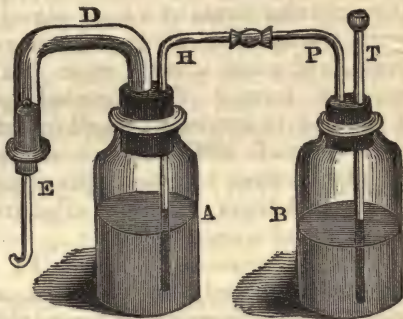
312. Sulphuretted hydrogen is obtained, by the process used [180] to procure hydrogen, a sulphuret being used instead of the metal itself. Thus, with sulphuret of iron, sulphuretted hydrogen will be formed, and sulphate of iron will remain in solution. $(\text{SO}_3 + \text{HO}) + \text{FeS} = \text{HS} + (\text{SO}_3 + \text{FeO}).$

313. Sulphuretted hydrogen is a colourless gas; its smell is like that of rotten eggs—which owe their peculiar odour to its presence. Its specific gravity is 1.77:—100 cubic inches weigh 54.891 grains. It is a combustible: and, when it is burned sulphur is deposited. It does not support combustion nor respiration. It is highly injurious to animals:—a horse has been killed, by an atmosphere containing but one part in 250 of this gas: air having only the one-eight-hundredth part of it, is poisonous to man; a cubic inch, introduced into the lungs, will cause instant death, although, in the intestinal canal, it is harmless. It will destroy life, by acting on only the surface of the body. Water absorbs, at ordinary temperatures, more than one volume, which is given out, by boiling; it is not absorbed, by a concentrated solution of common salt. If collected over mercury, it is slowly decomposed. Strong nitric acid decomposes it, immediately:—which may be exemplified, by wrapping a bottle containing it, in a cloth, dropping into it some nitric acid: then closing the mouth of the bottle, with the thumb, and shaking it—to bring the gas more rapidly in contact with the acid. An explosion, and flame are produced, but are not dangerous:—they arise from combustion, caused by the heat evolved, when the gases are prevented from expanding. Sulphur—which is deposited in the bottle—water, and nitrous acid are the results. $\text{SH} + \text{NO}_3 = \text{S} + \text{HO} + \text{NO}_2.$ Sulphuretted hydrogen is decomposed also, by chlorine—on account of the affinity of the latter for hydrogen. The results then, are, hydrochloric acid (HCl), and sulphur. Hence, chlorine purifies an atmosphere, rendered unwholesome by this gas. The acid properties of sulphuretted hydrogen are shown, by its reddening litmus paper: which it does, even when dissolved in water.

314. Sulphuretted hydrogen precipitates, as we shall find, a great number of the metals: sometimes, however, it requires

for this purpose, to be in combination with an alkali. If it is brought in contact with a solution containing the salt of an alkali or an earth, there is no precipitate: for the resulting sulphuret is soluble. Fig. 344 represents an apparatus, which has been found very convenient, for transmitting sulphuretted hydrogen through a solution.

FIG. 344.



The bottle B contains water, and pieces of sulphuret of iron. Sulphuric acid is poured in, through the funnel T—according as it is required. The sulphuretted hydrogen evolved, passes, by means of the angular tubes P and H—having a caoutchouc joint [94]—into the bottle A, containing cold water, which purifies the gas, and retains anything else, that may pass from B. It is transmitted, by the tube D—having a cork at E, into which is inserted a smaller tube—to the solution, which is to be acted upon.

315. When sulphuretted hydrogen is present, in large quantities, in the atmosphere, it darkens white paint—which contains *ceruse* or carbonate of lead. Some fine pictures have thus been injured, when the varnish was removed by time. But Thenard found that they might be perfectly restored, by oxygenated water [199]: the *black* sulphuret, being changed into *white* sulphate of lead. Sulphuretted hydrogen causes silver to tarnish with great rapidity; and it destroys the beautiful white colour of the subnitrate of bismuth, sometimes used by ladies, as a cosmetic [278].

Bisulphuret of hydrogen, &c., are not sufficiently interesting to claim our particular attention.

316. SELENIUM: *—*symp.* Se; *equiv.* 39.63. It is a very rare substance, and was discovered by Berzelius in 1818. It is found, united with metallic sulphurets, in the form of selenurets of the same metals.

317. It may be procured, from the sulphurets containing it, by adding eight times their weight of peroxide of manganese, and exposing the mixture to a low red heat, in a glass retort, the beak of which dips into water. The sulphur escapes, as sulphurous acid; and the selenium sublimes, either uncombined, or as selenious acid (SeO_2).—Any of the latter, which passes over into the water, will be reduced by the sulphurous acid.

* *Selēnē*, the moon, *Gr.*—a name suggested by its being, at first, mistaken for tellurium.

318. Selenium is a dark brown solid, having, when smooth, a metallic lustre. Its specific gravity is 4.320. It melts at a little above 212°: and boils at 650°—its vapour being of a deep yellow colour. It very much resembles sulphur, in its mode of combining, and, in the nature of its compounds—but, when burned in the air, it forms only an oxide (SeO). It gives to the oxidizing flame of a blow-pipe [101] a light blue tinge, and emits the smell of decayed horse-radish:—the one-fiftieth of a grain, will scent a large room. This odour is due to oxide of selenium, formed. Selenuretted hydrogen (SH) is a gas which, if inhaled in extremely small quantity, destroys for a time the sense of smell, and causes considerable injury to the lungs.

Sulphuretted hydrogen precipitates, in acid solutions containing selenium, a yellow sulphuret (SeS_2), soluble in hydro-sulphuret of ammonia.

319. PHOSPHORUS:—*ymb.* P; *equiv.* 31.32. It was discovered by Brandt, an alchymist, at Hamburgh, in 1669; and was formerly obtained, by a very tedious, and disagreeable process, from urine; but it is now prepared, from bones, four-fifths of which are phosphate of lime ($\text{PO}_5 + \text{CaO}$). Nature uses the salts of lime, for the framework of animals. When the carbonate predominates, it is “shell;” when the relative amount of phosphate is increased, it is “crust”—as in the shell of the lobster; when the phosphate of lime is in excess, it is “bone.”—I shall give, hereafter, the constituents of these substances.

320. After the bones are burned to a white powder, they are digested, for about two days, with half their weight of strong sulphuric acid: and enough of water to form them into a thin paste, is added. Sparingly soluble sulphate of lime ($\text{SO}_3 + \text{CaO}$), and soluble superphosphate of lime ($2\text{PO}_5 + \text{CaO}$) are produced. The latter, is to be dissolved out with water, filtered, and evaporated to the consistence of syrup: it is then to be mixed with powdered charcoal, equal, in weight, to one-fourth of that of the bones used. The carbon, being heated along with it in an earthen retort, takes oxygen from some of the phosphoric acid of the superphosphate, forming phosphate of lime ($\text{PO}_5 + \text{CaO}$), carbonic oxide [263], and carbonic acid [266]; and the phosphorus is driven off in vapour, and is condensed by the water into which the beak of the retort is plunged.

321. Phosphorus is, usually, a semi-transparent, and nearly colourless substance, which may be cut with a knife; but at 32° it is crystalline, and brittle. Its specific gravity is 1.77. It melts, at 108°: takes fire, in pure oxygen, at 80°—but, in common air, at 148°: and boils, at 550°. It burns slowly in the atmosphere, at ordinary temperatures, with the emission of light; but this slow combustion will be prevented, by olefant gas, the vapour of ether, or of oil of turpentine. It may be

* *Phōs*, light; and *phero*, I carry. *Gr.*

inflamed under water, by a current of chlorine, or, if the water is heated [124], by a current of oxygen.—When chlorine is used, terchloride of phosphorus (PCl_3) is formed; and this is decomposed, by the water, into hydrochloric (HCl), and phosphorous (PO_2) acids. $\text{PCl}_3 + 3\text{HO} = 3\text{HCl} + \text{PO}_2$.

If phosphorus is dissolved in ether, the solution will, on exposure to the air, become luminous, as will, also the face, and hands, if rubbed with it: this may be done, without any other inconvenience, than what arises from the disagreeable odour. If phosphorus and azote are kept in contact, they will unite; and the gas will become luminous, when brought in contact with atmospheric air.

Phosphorus seems to assume allotropic [154] conditions. For, when it is strongly heated and suddenly cooled, it becomes quite black; but it gradually assumes its ordinary appearance.

322. Phosphorus forms, with oxygen, oxide (P_2O ; 70·64); hypophosphorous acid (PO ; 39·32); phosphorous acid (PO_2 ; 55·32): and phosphoric acid (PO_5 ; 71·32). It forms several compounds with hydrogen, of which the most remarkable is phosphuretted hydrogen (PH_3 ; 34·32). It forms, with chlorine, protochloride (PCl_2 ; 137·73), and perchloride (PCl_5 ; 208·67): and combines also with other elements.

323. *Phosphorous acid* (PO_2) may be obtained, by throwing a current of chlorine, upon phosphorus placed in a thin glass vessel, and covered to the depth of some inches with water. The protochloride of phosphorus (PCl_2) which results, is immediately decomposed by the water, phosphorous and hydrochloric acids being produced. $\text{PCl}_2 + 3\text{HO} = \text{PO}_2 + 3\text{HCl}$. Evaporating the solution, to the consistence of syrup, drives off the hydrochloric acid, and leaves hydrated phosphorous acid behind.

324. *Phosphoric acid* (PO_5), as I have already remarked [27], is, according to circumstances, capable of combining with one, two, or three atoms of base. There is, therefore, a monobasic acid ($\text{PO}_5 + \text{HO}$), termed the *metaphosphoric*: a bibasic ($\text{PO}_5 + 2\text{HO}$), the *pyrophosphoric*: and a tribasic ($\text{PO}_5 + 3\text{HO}$), the ordinary phosphoric acid. It is found, combined with magnesia and ammonia, in the outer husks of all the grasses. Hence it is present in flour, and in beer: and sometimes forms very large concretions in the cæcum of millers' horses. It may be detected, in beer, by its forming a white precipitate, when ammonia is added.

325. PHOSPHURETTED HYDROGEN:—*symb.* PH_3 : *equiv.* 34·32. It is obtained, by *filling* a retort, containing a small quantity of phosphorus, with a solution of caustic potash. If any atmospheric air is allowed to remain in the upper part, an explosion

may occur.—This will, however, be prevented by letting up a little ether, the vapour of which, or of any of the essential oils, changes the gas produced, into one that is not spontaneously inflammable. When heat is applied, water is decomposed, hypophosphorous acid (PO)—which combines with potash—and phosphuretted hydrogen (PH_3) being formed. $4\text{P} + 3\text{KO} + 3\text{HO} = 3(\text{PO} + \text{KO}) + \text{PH}_3$. The phosphuretted hydrogen, as it rises from the water into which the beak of the retort is plunged, bursts into a flame: which is succeeded by a ring of smoke, consisting of a vast number of small rings revolving rapidly on axes, the planes of which are perpendicular to that of the general ring produced by them. The latter widens as it ascends, and will continue unbroken for a longer, or shorter period, according to the stillness of the air in the apartment. When the gas is transmitted into a jar of oxygen, the effect is very beautiful, but the experiment is not so safe. The retort must not be removed, until all the gas has been expelled by vapour of water.

326. Phosphuretted hydrogen is transparent, and colourless; it has a very disagreeable taste, and the smell of garlic. Its specific gravity is 1.185:—100 cubic inches weigh 36.7489 grains. It does not support either combustion, or respiration. Some persons believe, that the spontaneous combustion of the human body—of which several cases, seemingly well authenticated, are on record—arises from the production of this gas, by disease.

327. Phosphuretted hydrogen, not spontaneously inflammable, but exactly the same in composition, &c., as that which is, may be obtained, by heating hydrated phosphorous acid ($\text{PO}_3 + 3\text{HO}$) [323]. Water is decomposed, phosphoric acid (PO_5) and phosphuretted hydrogen (PH_3) being produced. $4(\text{PO}_3 + 3\text{HO}) = 3\text{PO}_5 + \text{PH}_3$. This gas may be set on fire. It is changed into the spontaneously inflammable kind, by nitric oxide, or nitrous acid gas. The spontaneous inflammability of phosphuretted hydrogen, arises from the presence of a highly volatile fluid (PH_2).

328. CHLORINE: *—*ymb.* Cl ; *equiv.* 35.47. It was discovered by Scheele in 1774; and was named by him “dephlogisticated marine acid,” because supposed to be hydrochloric acid deprived of its phlogiston [161]. It was afterwards called “oxy-muriatic acid”—being considered a combination of muriatic acid and oxygen: &c. It is found in enormous quantities in combination as chloride of sodium (NaCl) or common salt: and is obtained, by adding peroxide of manganese to hydro-

* *Chlōros*, green, *Gr.*, from its colour.

chlorig acid, and applying heat—after stirring the mixture, to allow any carbonic acid that may be present, to escape. Chloride of manganese—which remains in the retort—water, and chlorine are the results. $MnO_2 + 2HCl = MnCl + 2HO + Cl$. Deuto-chloride of manganese ($MnCl_2$) is first produced: but it is decomposed by a moderate heat. Since chlorine is absorbed by water at a low temperature, and it acts upon mercury, it must be collected over water heated to beyond 90° , or saturated with common salt. Or it may be collected without the use of any fluid: since, being heavier than atmospheric air, it will [226] displace the latter, from a jar into which it is transmitted.

329. Chlorine is of a greenish colour; and of a very disagreeable taste and smell. It is a supporter of combustion; but is not inflammable. Copper leaf, pulverized antimony, arsenic, or zinc, tinfoil, and phosphorus, burn in it, spontaneously. A wax taper introduced into it will continue lighted; but its brilliancy will be greatly diminished: and, as its hydrogen, only, combines with the chlorine, a dense black smoke, consisting of the carbon, will be produced. Paper dipped in oil of turpentine will take fire in chlorine: and, for a similar reason, large quantities of soot will be formed. Chlorine is irrespirable, being an irritant, and very suffocating gas. Its specific gravity is 2.47:—100 cubic inches weigh 76.5989 grains. Cold water absorbs two volumes of it, and then possesses most of the properties of the gas itself: but light causes the chlorine gradually to decompose the water, and form hydrochloric acid [HCl], by combining with its hydrogen. This tendency to unite with hydrogen, according to some chemists, gives to it the property of bleaching:—for, when it combines with that of decomposed water, the oxygen, which is liberated, burns the colouring matter. Hence, according to this theory, oxygen, is the real agent, in bleaching; and the result is the same, whether produced slowly, by exposure to atmospheric air, or more rapidly, by the use of chlorine, which affords oxygen in the nascent state [126]. The effect cannot be due to the chlorine itself, if the colour is not affected when the chlorine is dry—that is, when there is no water present, which may be decomposed: which has been stated. More recent researches, however, seem to show that the chlorine, in some cases actually combines with the colouring matter; that in others, it takes the place of hydrogen, in them; and that, in others, besides combining with, it more highly oxidizes them—water being decomposed.

330. The affinity of chlorine for hydrogen, causes it to be a powerful disinfectant:—it purifies the air from noxious effluvia,

by seizing upon the hydrogen they contain. The same property causes it, also, to act frequently as a very efficient oxidizing agent—by liberating oxygen, when it decomposes water, that it may combine with its hydrogen. Sometimes it more fully oxidizes a metallic oxide, by combining with a part of its metal—the displaced oxygen going to the other portions of the oxide, which thus becomes in a higher state of oxidation:—in this way, it changes protoxide into peroxide of iron. If chlorine is transmitted through sulphuric ether, the latter is decomposed, and the bubbles of gas inflame, at ordinary temperatures, as they ascend:—hydrochloric acid, and carbon are the results. At a pressure of about four atmospheres, chlorine becomes a bright yellow liquid; which is a non-conductor of electricity. In the form of gas, it may be kept in a bottle for a long time, if the ground glass stopper is well greased.

331. Chlorine forms, with oxygen, hypochlorous acid (ClO ; 43·47); chlorous acid (ClO_2 ; 59·47); perchlorous acid (ClO_3 ; 67·47); chloroso-chloric acid ($\text{Cl}_2\text{O}_3 = \text{ClO}_2 + 2\text{ClO}$; 210·41)—called by Sir H. Davy *euchlorine*; chloric acid (ClO_2 ; 75·47); perchloric acid (ClO_3 ; 91·47); and chloroso-perchloric acid ($\text{Cl}_2\text{O}_7 = \text{ClO}_3 + 2\text{ClO}_2$; 242·41). It forms with hydrogen, hydrochloric acid (HCl ; 36·47). With carbon, subchloride or dichloride (C_2Cl ; 47·47); protochloride (C_2Cl_2 ; 82·94); bichloride (C_2Cl_4 ; 82·94); and perchloride (C_2Cl_6 ; 118·41). With sulphur, dichloride (S_2Cl ; 67·47); and bichloride (SCl_2 ; 86·94). With phosphorus, protochloride (PCl_3 ; 137·73); and perchloride (PCl_5 ; 208·67). With boron, bichloride (BCl_2 ; 81·84). With silicon, chloride (SiCl_2 ; 92·29). It forms with carbon, chloro-carbonic acid (COCl ; 49·47), &c.

332. Sometimes chlorine unites with metallic oxides:—thus, with lime, it forms chloride of lime (CaOCl). At others, a chloride combines with an oxide of the same, or of a different metal, forming an oxy-chloride—or submuriate; thus, oxy-chloride of copper is produced [gal. 22], when sea water acts on copper.

333. Chlorine, in the free state, is detected by its odour. Also, by giving, with nitrate of silver ($\text{NO}_3 + \text{AgO}$), a white curdy precipitate, the chloride of silver (AgCl).—Nitric acid is liberated, and chloric acid (ClO) is formed, with the oxygen of the oxide, and a portion of the chlorine. $6\text{Cl} + 5(\text{NO}_3 + \text{AgO}) = 5\text{AgCl} + 5\text{NO}_3 + \text{ClO}_2$. The chloride is [opt. 120] blackened by exposure to light.—Organic matter must be present, to afford hydrogen, which combining with the chlorine forms, hydrochloric acid, metallic silver in a finely divided state being set free.

334. If the chlorine is in combination, the oxygen and nitric

acid go to the substance with which it was combined. Thus, when nitrate of silver is added to a solution of common salt (NaCl), chloride of silver, and nitrate of soda ($\text{NO}_3 + \text{NaO}$) are the results. $\text{NaCl} + (\text{NO}_3 + \text{AgO}) = \text{AgCl} + (\text{NO}_3 + \text{NaO})$.

335. Chlorine, as chloric acid, gives no precipitate with nitrate of silver.—The alkaline chlorates, however, when ignited, become chlorides, oxygen being disengaged: and most of the other chlorates are changed, by heat, into oxides—a mixture of chlorine and oxygen being evolved.

336. Chloride of silver may be distinguished from the iodide, which is yellow, by its whiteness: and by its being soluble in water of ammonia—the precipitate thrown down from the latter by nitric acid, not being dissolved by it, even at a boiling temperature. It may be distinguished from the cyanide—which, if ignited, yields metallic silver—by not being decomposed with heat; from the pyrophosphate, by becoming yellow, on being boiled with phosphate of soda; and from the bromide, by the latter giving off vapours of bromine, when heated with chlorine water.

337. Chloride of silver is dissolved, to a small amount, by a solution of common salt, or hydrochloric acid. It is this minute quantity which acts, when nitrate of silver is given as a medicine:—the nitrate is changed into chloride, by the hydrochloric acid of the gastric juice. If the chloride were quite insoluble, it would cause no effect:—many antidotes produce their beneficial results, by rendering poisonous substances insoluble.

338. The air hanging over the sea, will make a solution of nitrate of silver turbid, on account of the common salt (NaCl) it contains—the evaporating water having communicated to the solid, the property of evaporation, which it does not possess in the dry state [heat 88]. Hence, it is difficult to purify sea water perfectly, by distillation; since, a portion of the substances it holds in solution, rises along with it.

339. HYPOCHLOROUS ACID, BLEACHING SALTS, &c.—Hypochlorous acid:—*ymb.* ClO ; *equiv.* 43·47. It is remarkable only for its bleaching properties; and from its being, according to many chemists, a constituent of what are called “bleaching salts.” The old method of bleaching, by exposure to the air, was extremely tedious; that, in which chlorine, and some of its compounds, are employed, for the same purpose—and which was introduced only a few years ago—is rapid, and most complete. Chlorine may be used for bleaching, in several ways. It may be dissolved in the water, in which the cloth is steeped:—this is both economical, and effective; but it is injurious to the health of the workmen: and also, without great caution, to the

texture of the cloth. Or it may be passed into cream of lime [281]: and water being added, the cloth may be steeped in the mixture. Or, finally, chlorine may be transmitted into hydrate of lime: when a white powder, which has merely a faint odour of hypochlorous acid, and is the substance at present employed in bleaching, will be produced. Anhydrous lime would not absorb the gas.

340. According to some, the bleaching salt of lime consists of chlorine, combined with lime (CaOCl). According to others it is a compound of chloride and hypochlorite of lime [$\text{CaCl} + (\text{ClO} + \text{CaO})$]. In either case, it is supposed to consist of the same elements—since $2\text{CaOCl} = \text{CaCl} + \text{ClO} + \text{CaO}$. If chloride of calcium is present, it must be in combination; since, in a free state, it would cause the salt to deliquesce—which it never does, unless improperly prepared. If too large a quantity of chlorine is used in its manufacture, or if it is kept too long, it will become chlorate of lime, and chloride of calcium—after which, it will attract moisture, and will no longer bleach. When the bleaching powder is thrown into water, only a part of it is dissolved, and some hydrate of lime falls down: the latter not being converted into the bleaching compound, from, it is probable, the mechanical disadvantage, attending the use of the dry lime. If the lime were mixed with water, before it was combined with the chlorine, the whole of it would be dissolved.

341. Any acid will decompose the bleaching powder, and liberate the chlorine. Goods dyed red with madder, and stamped with tartaric acid thickened with gum, are bleached in the pattern—being acted on only where there is acid. Even the carbonic acid in water, or that of the atmosphere, will slowly disengage the chlorine.

342. The goodness of a bleaching salt may be ascertained, by finding how much of it will change a known quantity of protochloride of mercury (calomel, Hg_2Cl), suspended in water, into perchloride (corrosive sublimate, HgCl), which will be completely dissolved by that fluid. 23561 grains protochloride of mercury require 3547 parts chlorine to change it into perchloride.—Theoretically, the bleaching salt should contain 42·5 per cent. chlorine; but the best specimens have scarcely more than 40·32; and the generality of them only about 30 per cent. The determination of the quantity of chlorine in a bleaching salt, is termed “chlorimetry.”

343. A bleaching salt of potash, or soda, may be formed, by transmitting chlorine into solutions of their carbonates, until no more chlorine is absorbed:—the yellow colour of the fluid is due to the presence of free hypochlorous acid. Rather

complicated changes occur during the process; but the result is that the carbonates become hypochlorites.

High pressure steam is, sometimes, used instead of chlorine, for bleaching.

344. The solution of a bleaching salt, is employed as a disinfecting fluid. That of lime will answer the purpose, without the addition of water, if a large surface is exposed to the carbonic acid of the atmosphere. Chlorine itself, though highly effective, is in many cases, inadmissible.

345. The solution of a bleaching salt will, also, restore meat which is beginning to putrefy. That of soda is the most convenient, in this case: since the results are water, and common salt (NaCl): and the latter is useful, rather than the contrary.

346. CHLOROUS ACID:—*ymb.* ClO_2 ; *equiv.* 59·47. It is obtained, by acting on chloric acid, with an equal number of atoms of arsenious acid. Chlorous, and arsenic acids are the results. $\text{ClO}_3 + \text{AsO}_3 = \text{ClO}_2 + \text{AsO}_5$. A gentle heat separates the chlorous acid from the liquid, in the form of a greenish yellow gas. If the temperature employed is not very moderate, a violent explosion may happen—the gas being decomposed into chlorine, and oxygen. It bleaches powerfully.

347. PERCHLOROUS ACID:—*ymb.* ClO_2 ; *equiv.* 67·47. It is obtained, by decomposing chlorate of potash, in fine powder, with tolerably strong sulphuric acid. The chloric acid, is resolved into perchlorous (ClO_2), and perchloric (ClO_7) acids. $3\text{ClO}_3 = 2\text{ClO}_2 + \text{ClO}_7$. Bisulphate, and perchlorate of potash remain behind. The heat must be very gentle, or an explosion will take place. This gas, being heavier than atmospheric air, will displace the latter, from a jar [226].

348. Perchlorous acid is of a yellowish green colour, and an aromatic odour. It is condensed, by pressure, into a deep red fluid. It bleaches powerfully; and, on account of the facility with which, from almost no cause, it separates into its elements, it oxidizes energetically. If a few crystals of chlorate of potash, and a little phosphorus, are placed together, at the bottom of a tall glass, filled with water, and some strong sulphuric acid is conducted to them, by means of a long glass funnel, bubbles of perchlorous acid, in each of which the phosphorus burns, are produced: and thus combustion is effected, under water.

If perchlorous acid is heated, to even a little above 212° , it explodes, with a flash of light.

349. CHLORIC ACID:—*ymb.* ClO_3 ; *equiv.* 75·47. It is obtained, by adding to a solution of chlorate of barytes ($\text{ClO}_3 + \text{BaO}$) just enough of sulphuric acid, for saturation:—sulphate of barytes ($\text{SO}_3 + \text{BaO}$) will be thrown down, and chloric acid will remain in the fluid.

350. HYDROCHLORIC ACID:—*ymb.* HCl ; *equiv.* 36·47. It

was formerly called "spirit of salt," "marine acid," and "acid of salt," and, very commonly, muriatic acid:* but it is now generally termed, with greater accuracy, "hydrochloric acid"—which indicates its composition. It was first obtained, as a gas, by Priestly, in 1772. Light [opt. 119] will cause hydrogen and chlorine to combine and form this acid. It may be procured, very conveniently, from one part, by weight, of dried common salt (NaCl), which has been ignited, to decompose any nitre present, and two parts oil of vitriol. When heat is applied, the hydrochloric acid will be evolved, in the form of gas: and, according to the quantity of sulphuric acid, sulphate, or bisulphate of soda will remain in the retort.—The reasons given for forming a bisulphate in obtaining nitric acid [230] are applicable, in this case also: since the sulphate, or bisulphate, of soda is affected in the same way as the sulphate, or bisulphate, of potash: and there are, in both instances, the same motives, for adding enough sulphuric acid, to form a bisulphate. But, in obtaining the hydrochloric acid, it will be necessary to pour in the quantity of sulphuric acid, required to form the bisulphate, by degrees:—otherwise, a very slight increase of temperature will disengage the whole of the hydrochloric acid, at once, in the form of gas. And, on account of this mode of adding the acid, to mix the ingredients properly, it will be necessary to bring the bisulphate to the point of fusion. $\text{NaCl} + 2(\text{SO}_3 + \text{HO}) = \text{HCl} + [(\text{SO}_3 + \text{NaO}) + (\text{SO}_3 + \text{HO})]$. When only enough sulphuric acid to produce a sulphate is used, a mixture of sulphate of soda, and chloride of sodium results, hydrochloric acid being given off. And to make the sulphate and chloride act on each other, so as to disengage the remainder of the acid, such a heat is required, that the decomposition cannot be effected in vessels of glass. Moreover there is not, at the end of the process, enough water, to yield, by its decomposition, the required quantity of hydrogen:—hence chlorine, and sulphurous acid are evolved.

351. Hydrochloric acid is a colourless gas, having a strong taste, and a suffocating smell. Its specific gravity is 1.2695:—100 cubic inches weigh 39.3694 grains. It is neither inflammable, nor a supporter of combustion. It is irrespirable—causing spasm of the glottis. At low temperatures, under a pressure of about eighteen atmospheres, it becomes a liquid. Though an acid, when perfectly dry it will not act on vegetable colours. Its affinity for water is most remarkable. It will be absorbed, instantaneously, by a drop of that fluid, let up into the jar, in which it is. Or, if a tube hermetically sealed at one end is filled with it, then closed at the other

* *Muria*, sea salt. *Lat.*

by the thumb, and afterwards opened under water, the latter will rush up into the tube with great velocity. It will melt ice immediately, for the sake of the water. Whenever it escapes into the atmosphere, it forms dense white fumes, by its union with the hygrometric moisture. On account of this affinity for water, if its properties are to be examined, it must be collected over mercury.

352. *Liquid hydrochloric acid* is a solution of the gas, in water. The latter, at a temperature of 40° , absorbs 480 volumes: and the solution has a specific gravity of 1.2109. According to Thompson, a cubic inch of water, at 69° , absorbs 418 cubic inches; the specific gravity of the solution is then 1.958: and the bulk of the liquid is increased to 1.34 inches. If the solution contains one atom of absolute acid, and six of water, its specific gravity is 1.203. When its specific gravity is 1.094, its boiling point is 230° : and it distils unchanged. The liquid acid may be obtained, by transmitting the gas into a receiver containing distilled water, and cooled externally. Wolf's apparatus, fig. 340, may be used—the corks being secured with *fat lute*. It will be proper to combine the gas with a quantity of water equal, in weight, to that of the common salt: one-third of it—not necessarily distilled water—being mixed with the oil of vitriol, and allowed to cool, that the effervescence may not be too violent.

353. The first portion of hydrochloric acid evolved, contains sesquichloride of iron (Fe_2Cl_3), derived from the pans in which the salt was manufactured. Since it is very volatile, it mixes with the gas, and gives a yellow colour to the water of the Wolf's bottle E (fig. 340), in which it is condensed. This colour may be removed from the acid of commerce, by the addition of protochloride of tin (SnCl), which changes the sesquichloride of iron into protochloride (FeCl)—and becomes itself perchloride (SnCl_2). And, as neither the protochloride of iron, nor perchloride of tin is volatile, the acid may be freed from them by distillation. Hydrochloric acid is sometimes coloured by the presence of decomposed organic matter:—when strong, it acts on the organic substances, particularly if they are vegetable. Any sulphuric acid, which may pass from the retort, is retained in the Wolf's bottle.

354. The acid of commerce frequently contains arsenic, on account of the oil of vitriol, used in its manufacture, having been made with iron pyrites: this renders its purification difficult. For accurate experiments, therefore, it is well to use what is made in the laboratory. When it is produced, on the large scale, the sulphuric acid employed, is that which is obtained from the leaden chamber [302], and is not concentrated.

355. Hydrochloric acid, though to the chemist a most useful substance, is in certain processes, a source of considerable inconvenience, and expense. Thus, when sulphate of soda—which by means of carbonate of lime and charcoal is to be changed, into carbonate of soda—is made on the large scale from common salt, the hydrochloric acid, passing into the atmosphere, falls on, and utterly destroys the surrounding vegetation. To diminish the evil, chimneys of immense height are constructed; and the gases, being carried by them to a great altitude, are so much diluted, before they reach the earth, that the injury they produce is greatly lessened. The chimney of Muspratt, between Manchester and Liverpool, rises to the height of 492 feet:—it is $30\frac{1}{2}$ feet in diameter, at the base, and 11 at the top: and required, for its construction, a million of bricks.

356. In some cases, the acid is partially condensed, by transmission through flints wetted with water. But the best plan is, to combine the manufacture of bleaching powder [339] with that of the sulphate of soda. In this case, the chlorine, which is set free by decomposing the hydrochloric acid, as fast as produced, with peroxide of manganese [328], is condensed with lime [339]: and, the salts of iron and manganese being decomposed by exposure to the atmospheric air, at a red heat, the sulphate of soda is dissolved out from out the residue.

357. Hydrochloric acid is one of the ingredients of the “gastric juice” which is so important an agent, in the process of digestion. It is derived from the salt consumed with the food; and is the more necessary, in proportion as the food is difficult to be digested.

358. AQUA REGIA.* It is termed also “nitro-muriatic acid,” and by some, on account of being considered a new compound (NCl_2O_3), “chloro-nitrous acid:”—but the latter has been ascertained to be merely a mixture of chlorine, and hyponitrous acid. It is formed, by adding nitric to an equal quantity of hydrochloric acid: water, chlorine, and nitrous acid, being the results. $\text{NO}_3 + \text{HCl} = \text{HO} + \text{Cl} + \text{NO}_2$. When the two acids are mixed, a yellow fluid, having the smell of chlorine and nitrous acid, is produced; and heat is evolved. But the mutual decomposition of the acids, proceeds no farther than to saturate the liquid with chlorine: and if this is driven off by heat, or is combined with a metal, a new quantity is disengaged. The nitro-muriatic acid is, therefore, a source of chlorine in the nascent state, which [126] is very favourable to chemical combination; and, it dissolves gold, platinum, &c.—that are not acted upon, by either of the acids, separately.

* Royal water, *Lat.*—So called, because it dissolves gold, which was termed the “king of metals.”

359. IODINE :*—*ymb.* I; *equiv.* 126·85. It was discovered by Courtois, at Paris, in 1812 : and is found in nature, generally in combination with potassium or sodium, but never in a free state. It occurs in many springs, in the oyster, sponge, &c. The one-millioneth part, by weight, of marine plants is iodine. It was long known, that the ashes of the sponge, were useful in the cure of scrofula, &c. This gave rise to a suspicion, afterwards proved to be correct, that their utility was due to the iodine they contained ; and that substance has been successfully substituted for the ashes, previously employed. The inhalation of the vapour of iodine—by breathing air which has passed through water containing it in solution—and other applications of it, have been found beneficial in bronchitic affections, &c.

360. Iodine may be obtained, from *kelp*—the semi-fused ashes which remain, after sea weed has been burned. For this purpose, the kelp is lixiviated with water, which dissolves the soluble salts: and the solution being then concentrated to a certain point, common salt, with carbonate and sulphate of soda fall down, and may be removed: and, on cooling the liquor, chloride of potassium separates in the crystalline form, and may also be taken away. This concentration, and subsequent cooling, is repeated until these salts are exhausted, and only a dense, and dark liquid, containing the iodine—in combination, probably, with sodium—and various salts, remains. This liquid is to be rendered extremely sour by the addition of sulphuric acid, which, with the iodide of sodium, forms the double sulphate of soda and water, and hydriodic acid. $\text{NaI} + 2(\text{SO}_3 + \text{HO}) = [(\text{SO}_3 + \text{NaO}) + (\text{SO}_3 + \text{HO})] + \text{HI}$. During the process, carbonic acid, sulphurous acid, and sulphuretted hydrogen are given off—on account of other salts, also, being decomposed by the sulphuric acid. After a day or two, the liquor in which the hydriodic acid has been formed, is to be heated with peroxide of manganese. The latter, with the hydriodic acid, forms iodide of manganese and water, iodine being set free. $2\text{HI} + \text{MnO}_2 = \text{MnI} + 2\text{HO} + \text{I}$ [328]. The iodine, driven off by the heat, is condensed in the form of dark and brilliant crystalline plates, on the cold surface of a globular vessel filled with water, placed to intercept it. As the sulphuric acid would form also hydrochloric acid from the chlorides present, to prevent the simultaneous evolution of chlorine—which would immediately combine with the iodine, and form a chloride of iodine—only enough sulphuric acid to decompose the iodides must be used.

361. Iodine, in the form of vapour, is of a beautiful violet colour—whence its name; but this colour disappears, if the vapour is condensed. In the form of crystalline scales, its

* *Iōdēs*, violet coloured. *Gr.*

specific gravity is 4·948. It fuses at 225° , and boils at 347° :—but, when there is moisture present, it sublimes rapidly, at a heat below that of boiling water; it even evaporates, freely, at the ordinary temperature of the atmosphere. It stains the skin: but the discolouration is not permanent. It is not a conductor of electricity, and, therefore, although its lustre is strikingly metallic, it is not considered a metal. But, like some other bodies, it is said to be a conductor when its particles are brought into closer contact—which may be effected by fusion. Substances, undoubtedly metallic, have been found to lose their power of conduction, when in a certain state of division [elect. 20]. It is not inflammable: but it is a powerful supporter of combustion, and will immediately inflame phosphorus, brought in contact with it. It is an irritant poison. Water dissolves only the one seven-thousandth of its weight of iodine: but it is very soluble, in alcohol, or ether.—When taken into the stomach as an alcoholic solution, it is precipitated, on account of the dilution of the alcohol, by the other fluids found there. Iodine bleaches, like chlorine, and for the same reasons [329]: but not so powerfully.

362. Iodine forms, with oxygen, iodoso-iodic acid (I_5O_{10} ; 786·25); iodosous acid (IO_4 ; 158·85); iodic acid (IO_5 ; 166·85), and periodic acid (IO_7 ; 182·85). With hydrogen, hydriodic acid (HI ; 127·85) with nitrogen, teriodide (NI_3 ; 394·57) which is explosive, like the analogous compound of chlorine [257], though not altogether to the same extent. Iodine combines, also, with chlorine, &c.

363. Iodine, in the free state, is readily detected, by a *cold* solution of starch, with which it forms a deep blue compound—iodide of starch. Hot water dissolves the blue precipitate, and forms with it a colourless solution, which, however, regains its colour when cooled. If the iodine is in combination, it must be set free by an acid: or, by pouring on the solution containing it, the supernatant chlorine, from a bottle of chlorine water. The latter, to those who are not aware of the reason, appears to produce an exceedingly curious effect:—for, as the bottle of chlorine water seems merely to be held over the fluid containing the iodine and starch, the sudden change of colour seems quite unaccountable. If, in looking for iodine, too much chlorine is added, a chloride of iodine will be formed; and the blue colour will disappear.—Alkalies, or any other substances, forming compounds with iodine, would produce the same effect. Starch is an extremely delicate test.

364. BROMINE:—*symb.* Br.; *equiv.* 79·97. It was discovered in 1826, by Balard, of Montpellier: and is associated with chlorine, and iodine, in sea water, &c. It may be obtained, by transmitting a current of chlorine, through *bittern*—the “mother

* *Brōmos*, a disagreeable smell. *Gr.*

liquor," whence common salt has been procured: the fluid then acquires a yellowish hue, on account of the bromine, which is set free by the chlorine—the latter having, through a stronger affinity, taken its place in combination. The liquor is next to be agitated with ether, which will dissolve the bromine: and the resulting ethereal solution, which floats on the top, is to be removed, and potash is to be added to it. Bromide of potassium (KBr), and bromate of potash ($\text{BrO}_3 + \text{KO}$) will be formed. $6\text{Br} + 6\text{KO} = 5\text{KBr} + (\text{BrO}_3 + \text{KO})$. On separating the ether, by evaporation, and fusing the mixed salt which remains, the bromate will be changed into bromide of potassium, in the same way as chlorate is changed into chloride of potassium [157]. Sulphuric acid and peroxide of manganese being then added to the bromide, and heat being applied, bromine will be evolved. The changes, which take place, are analogous to those occurring, when chlorine is obtained, from a chloride, or iodine, from an iodide.—The bromide of potassium and sulphuric acid, form the double sulphate of potash and water, and hydrobromic acid. $\text{KBr} + 2(\text{SO}_3 + \text{HO}) = [(\text{SO}_3 + \text{KO}) + (\text{SO}_2 + \text{HO})] + \text{HBr}$. The hydrobromic acid and peroxide of manganese, form bromide of manganese and water, bromine being set free. $2\text{HBr} + \text{MnO}_2 = \text{MnBr} + 2\text{HO} + \text{Br}$.

365. Bromine, at ordinary temperatures, is a deep red fluid by transmitted, but a black by reflected light. Its odour is very disagreeable, and its vapour highly dangerous, when inhaled even in very small quantities. And if, by incautiously opening the bottle in which it is contained, the smallest particle gets into the eye, that organ is for ever destroyed. It is a non-conductor of electricity. Its specific gravity is 2.97. At ordinary temperatures, it gives off fumes resembling, in appearance, those of nitrous acid: and, unless kept in water, its vapour is sometimes disengaged in such quantities, as to burst the bottle. It solidifies at a temperature of 4° , and boils at 116° . Like chlorine, it sets fire to some of the metals. It bleaches, but leaves a yellow stain. It is sparingly soluble in water; but dissolves abundantly in alcohol, and ether.

366. Bromine forms, with oxygen, bromic acid (BrO_3 ; 119.97). With hydrogen, hydrobromic acid (HBr ; 80.97). With sulphur, bisulphuret (BrS_2 ; 111.97). With phosphorus, two phosphurets (PBr_3 ; 271.23, and PBr_5 ; 431.17). It unites, also, with chlorine, and iodine, &c.

367. Bromine is recognised, by giving, with nitrate of silver, a curdy white precipitate, which dissolves with difficulty in water of ammonia: and which, heated with chlorine water, evolves vapour of bromine. It gives, with acetate of lead, a white precipitate that, unlike chloride of lead, does not dissolve in water. It gives, with starch, a yellow precipitate.

368. FLUORINE:—*symb.* F; *equiv.* 18.86. It has such strong

affinities, that it is not certainly known to have ever been insulated. It is obtained, most probably, when, in looking for it, vessels are used, which consist of a substance—fluor spar, for example—already saturated with it. If dry chlorine is, with this precaution, transmitted into fluoride of mercury (HgF), heat being applied, a colourless gas, which acts violently on metallic foils, results. $\text{HgF} + \text{Cl} = \text{HgCl} + \text{F}$. This, however, may be chloride of fluorine.

369. Fluorine does not unite with oxygen. It forms, with hydrogen, hydrofluoric acid (HF ; 19·86). With phosphorus, terfluoride (PF_3 ; 87·90). It combines with sulphur, &c.

370. HYDROFLUORIC ACID:—*ymb.* HF ; *equiv.* 19·86. It is the most important of all the compounds of fluorine: and is obtained, by acting on Derbyshire spar (CaF), reduced to powder, with twice its weight of strong sulphuric acid: and heating the mixture, in a large leaden retort. Hydrofluoric acid distils over, and must be collected in a receiver cooled with ice:—sulphate of lime is left behind. $\text{CaF} + (\text{SO}_3 + \text{HO}) = \text{HF} + (\text{SO} + \text{CaO})$.

371. Hydrofluoric acid is a colourless liquid. Its specific gravity is 1·0609: but water, for which it has a strong affinity—though a lighter fluid—increases its density, the mixture being accompanied by condensation, the evolution of heat, and a hissing noise, like that produced by plunging red hot iron into water. It boils at 60° , but, at a temperature of 59° , unless the vessel in which it is kept is well stopped, it escapes in dense white fumes. It is most corrosive, and acts so powerfully on animal matter that even its vapours produce malignant ulcers. Hence, on account of its dangerous nature, it is usually prepared in a dilute state—water being, for this purpose, put into the receiver, into which it is distilled. It does not act on gold, silver, platinum, or lead; but it acts powerfully on the solder, with which vessels are joined. It dissolves silicic, titanitic, molybdic, and tungstic acids.

372. The effect, produced by this acid on glass—and which arises from its affinity for silicon—enables us to engrave that substance, by means of it, with great facility. Bottles for the laboratory, may be labelled, by coating them, where they are to be protected from the acid, with bees-wax: then drawing the letters, &c., in the latter, so as to uncover the surface of the glass where it is to be acted upon; and afterwards, holding the bottle over the gas, as it is disengaged from fluor spar, by means of sulphuric acid [370]—great care being taken [371], to prevent the vapours from coming in contact with the skin, or very painful wounds will be produced. The siliceous glass (SiO_2)—contained in the glass—and the hydrofluoric acid, form terfluoride of silicon (SiF_3) and water. $\text{SiO}_2 + 3\text{HF} = \text{SiF}_3 + 3\text{HO}$. Without proper precaution, other glass vessels, which are near, will be

dimmed on their surfaces. Hydrofluoric acid was first used to engrave glass, at Nuremberg, in 1670; but the nature of the process was kept secret.

373. SILICON:—*symb.* Si ; *equiv.* 21·35. Sir H. Davy first obtained it, by bringing the earth silex in contact with the vapour of potassium, silicate of potash and silicon being the result. But it is now procured, by means of the double fluoride of silicon and potassium ($\text{SiF}_3 + \text{KF}$), dried at a temperature approaching to redness, and heated in a hard glass tube in contact with potassium (K): fluoride of potassium is formed, and silicon is set free. $(\text{SiF}_3 + \text{KF}) + 3\text{K} = 4\text{KF} + \text{Si}$. The fluoride of potassium being dissolved out, silicon is left behind.

374. Silicon is a dull brown powder, having no metallic lustre, and being incapable of conducting electricity:—it is not, however, yet ascertained, with certainty, whether or not it is a metal. It burns brilliantly, in oxygen, on account of the small quantity of hydrogen, generally, in combination with it: and it is soluble in a mixture of nitric and hydrofluoric acid:—but it is rendered quite incombustible, and insoluble, by heating in a closely covered vessel.

375. Silicon forms with oxygen, silicic acid (SiO_2 ; 45·35)—or silex. With chlorine, chloride of silicon (SiCl_4 ; 127·76). With fluorine, fluoride of silicon (SiF_4 ; 77·93). This gives rise to a double fluoride of hydrogen and silicon ($\text{SiF}_4 + \text{HF}$) or hydrofluosilicic acid, the hydrogen of which, in the formation of *fluosilicates* or *double fluorides*, is replaced by a metal;—which is exemplified by the fluosilicate of potassium ($\text{SiF}_3 + \text{KF}$).

376. SILEX:—*symb.* SiO_2 ; *equiv.* 45·35. It is called, also, silicic acid: and is found in the outer parts of the leaves, and the stalks of all the grasses—in the form of silicate of potash. It is present in most minerals; and constitutes the base of the quartz family. Silex may be obtained, by melting in a platinum crucible, a mixture containing equal weights of carbonate of potash ($\text{CO}_2 + \text{KO}$) and carbonate of soda ($\text{CO}_2 + \text{NaO}$): and, when the mixture is in a state of fusion, dropping powdered flint into it, in small quantities at a time. The flint will be dissolved, and its silex will combine with the potash and soda, forming silicates of these alkalies, the carbonic acid being driven off.—The carbonate of soda, renders the compound more fusible, and soluble. When flint is no longer dissolved, water having been added, the solution is filtered, and an acid is poured into the clear liquor. This causes the silex to precipitate, as a white gelatinous hydrate: which being dried and heated, becomes a gritty insoluble powder.

377. The specific gravity of this powder is 2·66. It is fusible under the oxyhydrogen blow-pipe, forming a colourless glass,

* *Silex*, a flint. *Lat.*

very plastic, and ductile. Being slightly soluble, in the gelatinous state, it is sometimes found in mineral waters. If a dilute alkaline solution of silex is decomposed by an acid, the liberated silex remains dissolved: but it is precipitated, by concentration: and is rendered insoluble, by evaporation to dryness. It is difficult to explain the great difference, between silex in the soluble, and insoluble states. When it is combined with an alkali, if the latter is relatively considerable in quantity, the silicate dissolves in water.

378. Silex, though an acid, does not redden litmus paper [19]: but it forms salts with oxides, disengaging carbonic, and even sulphuric acid—as when it decomposes the sulphate of soda, in crude potash, at a high temperature. The whole of the sulphuric acid will not be separated, in this case, unless resolved into sulphurous acid and oxygen, by the agency of carbon.

379. The composition of silicic acid is not quite certain. There is reason to suppose that it is SiO_2 :—there may even be two compounds, one of them SiO_2 , and the other SiO_3 . A similar doubt exists, as to its other compounds.

380. MANUFACTURE OF PORCELAIN. Silex is a very important constituent of both porcelain and glass: this will, therefore, be a convenient time to examine the manufacture of these substances.

The production of porcelain in China is so ancient, that its commencement is lost in the most remote antiquity. It was long admired by Europeans, as beautiful but inimitable: until a Saxon chemist, while endeavouring to discover the best material for crucibles, accidentally found the mode of forming it.

381. Porcelain consists, principally, of two ingredients, silex, and the earth alumina (Al_2O_3). It necessarily contains plastic and infusible substances, bound together by one that is fusible.—Alumina constitutes the former; silex, generally in combination with lime and potash, the latter. When the porcelain is good, a part of it is completely, and the rest not at all vitrified; the entire of bad porcelain is semi-vitrified. Good porcelain, such as the Chinese, and the Saxon, are not affected by a high temperature: bad is completely fused by it.

382. The excellence of porcelain depends on the relative proportions, and the purity of its ingredients. When these are of a very inferior kind, they constitute merely the earth of which bricks, tiles, &c., are made. The Chinese are particularly careful in selecting, purifying, and intimately blending them. Defective materials may, however, to a certain extent, be improved. The larger the proportion of silex, the whiter the porcelain, but the more liable it is to crack. Lime increases the fusibility of the porcelain earth:—silex, alumina, and lime fuse, if mixed together, though each, when separate, is infusible.

383. The porcelain clay, having been rendered sufficiently fine, is triturated with water, moulded together, and formed into the proper shape: after which, being baked, it constitutes what, from its appearance, is called "biscuit." In this state, it is used for various purposes: being employed, in galvanic experiments [gal. 35], &c. It is often used in cooling wines: for, since the water that is placed in it passes gradually from its interior, to its exterior, on account of its porosity, great cold is produced [heat 93], by evaporation at its outer surface.

384. When the porcelain has been baked, it is ready for the designs, with which it is to be embellished. The colours must be such as are capable of withstanding a very intense heat: and they generally consist of metallic oxides which, during the subsequent part of the process, are fused, so as to constitute *stained glass*—in minute quantities indeed, but of exactly the same nature as what I shall describe presently. Porcelain is often painted with great care, and extraordinary skill. Some specimens, which I saw in the museum of porcelain at Dresden, are scarcely to be distinguished from exquisite works in oil. The landscapes, &c., which decorate the ordinary kinds, are almost always obtained—and with great facility—by means of engravings on tissue paper, from copper plates. When they have been left adhering, for some time, to the porcelain, the latter is steeped in water: after which, the paper is rubbed away, without removing the impression. This method of ornamenting porcelain is extremely simple: but it is of comparatively recent date. By means of it, the tables of the poorest may be furnished, at a trifling expense, with articles, the convenience and beauty of which are not duly appreciated, from the ease with which they may now be obtained. It is said to have been accidentally discovered, by a workman throwing a newspaper, in which his food had been wrapped, among some vessels that were in process of manufacture. The substance of the paper was destroyed: but the letters remained, and were coated by the glazing.

385. Porcelain is glazed, by a metallic oxide, by a glass, or by an enamel. When it is bad, as it will not bear a high heat, without melting, it requires an easily fusible glazing—obtained by the use of oxide of lead, which, with some of the silix belonging to the porcelain, forms a silicate. This kind of ware looks well enough, for a time; but the glazing is cracked all over, by hot water: and, being poisonous, and at the same time soluble in a variety of fluids, it becomes, frequently, a source of danger. Porcelain is sometimes covered with a glass formed by felspar, one of the ingredients of quartz—a complicated substance, consisting of silix, alumina, potash, fluoride of calcium, oxide of manganese, and oxide of iron. In other cases,

common salt, thrown into the furnace which contains the porcelain to be glazed, is diffused, in vapour, through the different articles, by the very elevated temperature : and its sodium unites with silex, at their surfaces. Glass, and hydrochloric acid are formed, water being decomposed. $\text{SiO}_2 + \text{NaCl} + \text{HO} = (\text{SiO}_2 + \text{NaO}) + \text{HCl}$. Other substances, also, are employed for the same purpose. Enamel is a species of glass, containing silex, with the oxides of tin and lead :—the oxide of tin gives whiteness, and that of lead fusibility.

386. Porcelain is now very frequently used, for statues, groups, &c. : and often, when they are not large, with great success. If their size is too great, it is difficult, and indeed—as appears from the most successful examples to be seen in Dresden, &c.—impossible to bake them, without producing cracks, and other serious blemishes.

387. MANUFACTURE OF GLASS. The discovery of the mode of forming glass, is said, by Pliny, to have been made accidentally, by some Phœnician merchants who, when cooking their victuals on the sand, placed lumps of soda to support the vessels over the fire. The soda and the sand, acted on by the heat, is supposed to have produced glass. But the temperature could not possibly have been sufficiently high to fuse these substances together.

388. Both Pliny and Strabo, give such accounts of the glass houses of Sidon, and Alexandria, as show that the ancients were acquainted with the methods of cutting, grinding, colouring, and gilding glass. Nevertheless, it was, in ancient times, an extremely costly substance. Perfectly transparent vessels, were then very rare, and brought enormous prices.—Nero gave £50,000, for two glass cups with handles. Glass has been observed, in windows at Pompeii : but it must have been rarely used for that purpose, until the third century :—and its general adoption did not take place, until long afterwards.

389. A means of rendering glass malleable, is said to have been found out, in the reign of the Emperor Tiberius ; and again, in that of Louis XIII. But, in both cases, punishment—in the former that of death—was the only recompense bestowed on the discoverers ; and their secret, if it ever existed, died along with them. Pieces of glass, taken from an old pit twelve feet deep, were, indeed, found by Colladon to be flexible, and so soft, that they might be cut with a knife. But they became hard, and brittle, on being exposed to the air for a few hours.

390. Glass is essentially a combination of silicates, each of which, if used separately for the purpose, would be attended with certain inconveniences. Potash and soda—but particularly the former—render glass easy of fusion. Glass made with

potash will bear to be remelted, several times, without its alkali being driven off by the heat, &c., and its being, therefore, rendered less fusible. Continued heat will drive away all the alkalies. Soda communicates a bluish green tinge to glass, but increases its brilliancy. The silicates of potash and soda never crystallize; those of lime and the protoxide of iron do:—but their tendency to crystallization may be diminished, by silicate of alumina, and may be entirely prevented, by the addition of silicate of potash. Alumina increases the difficulty of fusion; oxide of lead produces an opposite effect. Two silicates, in combination, melt at a lower temperature than the mean of their fusing points. When glass is left a considerable time soft, without being melted, the silicates separate, and the less fusible, by crystallizing, render the glass opaque, and form the substance known as “Reamur’s porcelain.” If the silex, used in manufacturing glass, has not been made sufficiently fine—by heating it to redness, then throwing it into water, and afterwards carefully trituring it—white spots will appear. These are due to uncombined silex.

391. When carbonate of potash, or of soda, is employed in making glass, the carbonic acid is driven off by the mere application of heat; but [378] if sulphate of soda is one of the materials, carbon must be added, to decompose the sulphuric acid, and form carbonic oxide with some of its oxygen. If the mixture to be vitrified contains chloride of sodium, the latter is decomposed, by flame charged with moisture, hydrochloric acid and oxide of sodium being produced [385]:—but some of the soda is wasted, as chloride of sodium is volatilized by a high heat.

392. The green colour, perceived in some kinds of glass, is due to the presence of black oxide of iron. A little peroxide of manganese changes this into peroxide; and, by losing some of its oxygen, is itself changed to protoxide. The small quantity of peroxide of iron, which results, will be sufficient to give only a very slight yellowish brown tint. Nitre would change the manganese, back again to peroxide. If there is an excess of peroxide of manganese it will become, at a red heat, sesquioxide, which imparts a deep amethystine red tint:—a stick of wood thrust into the “metal,” as the melted glass is called, would remove this colour, by taking oxygen from the manganese. If carbon is present, as an impurity, it is banished by peroxide of manganese, which gives to it a portion of its oxygen. When the iron is peroxidized by arsenious acid (AsO_3), metallic arsenic is evolved, in vapour. Bottles containing much alumina, are acted upon by tartaric acid, and spoil wine.

393. The principal kinds of glass are flint glass, crown glass, broad glass, bottle glass, and plate glass. *Flint glass*, one

species of which is also called "crystal," derives its name, from having been formerly made with flints—and, probably, also from its appearance. It is very beautiful, and has a high refractive power. It is employed, very extensively, in the construction of optical instruments. Its ingredients, like those of porcelain, and of the other kinds of glass, are united by different manufacturers, in different proportions. It, sometimes, consists of silex, soda—or potash—oxide of manganese, and oxide of lead. Caustic potash, carbonate of ammonia, &c., renders it extremely brittle, particularly when its surface has been scratched or roughened. Hence, bottles containing these substances, occasionally fall in pieces, after being used for some time.

394. *Crown glass* is very hard. It consists of silex and potash—or soda: and, sometimes, other substances, to correct its impurities. It is frequently used, as window glass.

395. *Broad glass* is coarser than crown glass. It is manufactured from soapboilers' waste, consisting chiefly of lime and silex, with chlorides of potassium, and sodium, some caustic alkalies, and alkaline carbonates.

396. *Bottle glass* is made of any sea or river sand, lime—sometimes clay—and an alkali: and requires a high temperature, for fusion. It is an excellent material, for vessels intended to hold substances having corrosive properties.

397. *Plate glass* is manufactured from sand, lime, and potash, or soda—to increase its fusibility [390]; also substances are applied to render it colourless. It is poured on perfectly smooth metallic plates; and, while fluid, is rolled into sheets. The bronze slab, used for this purpose, at St. Gobin, weighs 50,000 lbs., and cost £4,000. The cylinder, with which it is rolled, often weighs several cwt.

398. It is curious that good specimens of the different kinds of glass, according to the most careful analyses, approximate very closely to the following formulæ:—

Flint glass	= $6\text{KO} + 9\text{PbO} + 20\text{SiO}_3$.
Crystal	= $\text{KO} + 2\text{PbO} + 8\text{SiO}_3$.
White crown glass	= $\text{KO} + \text{CaO} + 3\text{SiO}_3$.
Bottle glass	= $\text{KO} + 8\text{CaO} + 2\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3 + 8\text{SiO}_3$.
Plate glass	= $2\text{NaO} + \text{CaO} + 6\text{SiO}_3$.
Window glass	= $3\text{NaO} + 5\text{CaO} + 12\text{SiO}_3$.

399. Glass requires to be *annealed*, that is, cooled down gradually to the temperature of the atmosphere; or it would, of itself, break into pieces.—What are called "Rupert's drops" illustrate this in a very striking manner. They are formed of glass poured, when melted, into water: and if their larger end is broken, nothing remarkable occurs; but if their smaller, they fly into powder, with a loud noise. Annealing would prevent this.

400. The process of annealing, to be perfect, requires great care. The properties of light [opt. 246] enable us to detect unannealed glass. It may be known to be sufficiently annealed for chemical purposes, by its not breaking with boiling water. If it is acted upon, by water, or acids, it is of little use, in the laboratory. Distilled water, or hydrochloric acid, boiled in it for some time, should, when evaporated, leave no residuum.

401. The art of staining glass is very ancient.—The Emperor Adrian received stained glass goblets, as a present, from the Egyptian priests.

Sometimes the glass is coloured through its entire substance; at others, only to a greater or less depth from the surface:—porcelain is never coloured, otherwise than superficially. When glass is stained only on its surface, beautiful patterns, &c., may be produced, by grinding it off from parts which are intended to be colourless.

402. *Yellow*. A dirty yellow is obtained by using charcoal: but if the quantity of this substance exceeds a certain amount the tint becomes brown. A bright yellow is imparted, by oxide of uranium; as this substance, however, generally contains traces of iron, there is a tendency to green, in the tint produced by it. Oxide of silver, or chromate of lead, also, will give a yellow.

403. *Blue* is obtained, with oxide of cobalt (CoO)—the tint being more intense, if the glass contains no lead.

404. *Green* is produced by protoxide of iron; or, a more beautiful shade by oxide of copper (CuO). A grass green, by sesquioxide of chromium (Cr_2O_3); and an emerald green, by oxides of copper, and iron.

405. *Red* is obtained, by using peroxide of iron—but the resulting tint is brownish; or by suboxide of copper (Cu_2O), which is ascertained to be the colouring matter of red glass, found at the villa of Tiberius, in the island of Capri. The tint, produced by it, does not make its appearance, until the glass has been cooled, and then reheated:—the reason of which has not been clearly ascertained. The colour derived from this substance is of such intensity, that it is difficult to use a quantity so small, as not to render the glass opaque. A scarlet, carmine, rose, or ruby red, may be imparted by oxide of copper. Peroxide of manganese [392] gives an amethystine tint.

406. A *purple* is produced, by oxide of gold.

407. A *flesh colour*, by oxide of iron and alumina.

408. *Black*, being the absence of all colour, cannot be imparted, without destroying transparency; and it is generally obtained, by means of some tint which is so intense [405], that opacity results from it.

409. Mixed colours are often produced, by combining the substances, that give the tints of which they consist.

410. *Gilding of glass.* Glass is gilt, by rubbing on it, with a brush, oxide of gold—precipitated from a solution of the chloride, by caustic potash—mixed with anhydrous borax, and then with oil of turpentine, or gum water. When heat is applied, the oil of turpentine evaporates, or the gum is burned off, and the borax melts—so as to fix the reduced gold firmly to the surface. A fine polish is produced, by the burnisher—the gold being at first dull, and of a yellowish brown colour.

411. SOLUBLE GLASS was known to the alchymist, Van Helmont. It is very frequently used to deprive substances, impregnated with it, of their combustibility. When an excess of alkali is united with silex, the resulting glass [377] is soluble. If silex is fused with an excess of carbonate of potash, two atoms of silex combine with three of potash, and a very deliquescent glass is produced. When a solution of caustic potash is saturated with precipitated silex, and the solution is evaporated, a glass consisting of eight atoms silex, and three of potash is obtained. This is more useful than the former, since it is not deliquescent; and, though soluble in hot, is nearly insoluble, in cold water.—It is “soluble glass:” and may be economically obtained, sufficiently pure for ordinary purposes, by completely vitrifying in a crucible 15 parts powdered quartz, or pure sand, 10 parts potashes of commerce, and one part charcoal—to decompose the sulphuric, and carbonic acids. The impurities, contained in the result, are separated by pulverizing, and exposing to the air:—the salts, of which they consist, then attract moisture, and being easily removed by cold water, the residual glass is washed with that fluid. A dilute solution of this glass is decomposed by the carbonic acid of the atmosphere.

412. Linen, &c., the fibres of which are coated with soluble glass, cannot be burned. For, when heat is applied, the glass melts around them, and excludes the air [163].

413. It is sometimes employed as a kind of paint—being mixed with a variety of materials, and used to render woodwork incombustible. But, though it is very conveniently applied, in this way, it is difficult to find substances by which it is not decomposed. It answers, also, as a cement, for porcelain vessels; and for many other purposes.

414. When chalk, or gypsum, is saturated with soluble glass, and exposed to the carbonic acid of the atmosphere, it is impregnated to a considerable depth with silex, and becomes nearly as hard as marble. Objects, therefore, consisting of these substances, may thus be rendered very durable, and capable of a high polish.

415. If ordinary glass contains too much alkali, it approximates to the nature of soluble glass; and its tendency to attract moisture, renders it unfit for electrical purposes [elect. 20].

416. FLUORIDE OF SILICON:—*ymb.* SiF_3 ; *equiv.* 77·93. It is obtained, by mixing together, in fine powder, fluor spar and sand—or glass, and heating the mixture with oil of vitriol in a large vessel, as it swells up very much. The fluoride of calcium silex and sulphuric acid, give hydrated sulphate of lime ($\text{So}_3 + \text{CaO} + \text{HO}$) and fluoride of silicon. $3\text{CaF} + \text{SiO}_3 + 3(\text{SO}_3 + \text{HO}) = 3(\text{SO}_3 + \text{CaO} + \text{HO}) + \text{SiF}_3$. It is by some, considered to be SiF_3 , and then, silicic acid being SiO_2 [379], $2\text{CaF} + \text{SiO}_2 + 2(\text{SO}_3 + \text{HO}) = 2[(\text{SO}_3 + \text{CaO}) + \text{HO}] + \text{SiF}_3$.

417. It is supposed by many chemists, that, when the silex, fluoride of calcium, and sulphuric acid, are heated together, the fluoride of calcium first forms hydrofluoric acid and lime, water being decomposed. $\text{CaF} + \text{HO} = \text{HF} + \text{CaO}$. And that, then, the hydrofluoric acid, lime, and sulphuric acid form hydrated sulphate of lime, and fluoride of silicon, water being reproduced. $3(\text{SO}_3 + \text{HO}) + \text{SiO}_2 + 3\text{CaO} + 3\text{HF} = 3(\text{SO}_3 + \text{CaO} + \text{HO}) + \text{SiF}_3 + 3\text{HO}$.

418. Fluoride of silicon is a colourless, transparent gas: which must be collected over mercury, since it is decomposed by water. Even the moisture of the atmosphere changes it into white vapour, water being decomposed, hydrofluosilicic acid ($\text{SiF}_3 + \text{HF}$) being produced, and silex disengaged. $4\text{SiF}_3 + 3\text{HO} = 3(\text{SiF}_3 + \text{HF}) + \text{SiO}_2$.

419. When it is intended to obtain *hydrofluosilicic acid* in solution, the gaseous fluoride of silicon is passed into a vessel of water, on the bottom of which is some mercury, into which the tube, conveying the gas to be decomposed, dips. If the extremity of the tube were placed in water, it would soon be stopped up, by the silex which is disengaged. The latter may be removed, by straining through a fine linen cloth.

420. When a solution of hydrofluosilicic acid is heated, fluoride of silicon is evolved: and hydrofluoric acid, which would act on the vessel, if of glass [372], remains. If it is added to a solution, containing potash, or barium, sparingly soluble fluosilicate of potash—or of barium—is precipitated. Hydrofluosilicic acid is, by some considered to be ($\text{SiF}_3 + \text{HF}$); its composition, like that of the other compounds of silicon [416], not being yet determined, with certainty.

421. BORON,* *ymb.* B; *equiv.* 10·90. It is obtained, by acting on fluoborate of potash ($\text{BF}_3 + \text{HF}$) with potassium. The terfluoride of boron is decomposed, its fluorine uniting with potassium, and boron being set free. The same changes occur as when silicon [373] is produced in a similar way.

422. Boron is a dark olive substance; it is a non-conductor

* So called, from its being the base of boracic acid, found in Borax (borate of soda, $3\text{Bo}_3 + \text{NaO} + 10\text{Ac}$).—The latter derives its name from *buruk*, an Arabian word signifying brilliant.

of electricity; and is insoluble in water, and other neutral fluids. At a temperature of 600° , it forms, with oxygen, boracic acid. Also, when boiled with nitric acid, or ignited with the carbonate, or nitrate of potash.

423. It forms, with chlorine, &c., compounds analogous to those of silicon, already mentioned. And the same uncertainty exists as to their nature. Some chemists believe that boracic acid is BO_3 , while others consider it to be BO_2 . Some believe chloride of boron to be BCl_3 , while others describe it as BCl_2 : and thus of the rest.

424. Fluoride of boron (BF_3); and hydrofluoboric acid ($\text{BF}_3 + \text{HF}$) &c., are obtained in the same way as fluoride of silicon, hydrofluosilicic acid, [416, &c.]

CHAPTER IV.

THE METALS: their General Properties, 425.—Aluminum, 430.—Antimony, 435.—Arsenic, 439.—Barium, 444.—Bismuth, 453.—Cadmium, 457.—Calcium, 461.—Cerium, 469.—Chromium, 472.—Cobalt, 478.—Columbium, 484.—Copper, 488.—Didimium, 498.—Erbium, 499.—Glucinum, 500.—Gold, 503.—Ilmenium, 510.—Iridium, 511.—Iron, 515.—Steel, 524.—Lanthanum, 539.—Lead, 541.—Lithium, 551.—Magnesium, 555.—Manganese, 559.—Mercury, 565.

425. THE METALS; THEIR GENERAL PROPERTIES, &c.—The metals are opaque substances, conductors of heat, and of electricity; they have a peculiar and well-known lustre, termed “metallic;” and are all *positive* electrics [gal. 62]. They differ extremely in their tenacity [mech. 31], their malleability, ductility, hardness, volatility, and density; and in the facility with which they combine with non-metallic elements. Their tenacity is greatly injured, by annealing. Some metals are found “native,” that is, uncombined with other elements. Some are united with arsenic, with chlorine, iodine, sulphur, or an acid—but, most usually, with oxygen. Some have only one; others, several oxides. Some metallic oxides, as those of gold, silver, mercury, and platinum, may be reduced, by heat alone: others, require heat, and a combustible—a stream of hydrogen, for instance, or charcoal. Some are reduced by deoxidizing substances: such as phosphorous acid (PO_3), which, added to a solution of oxide of mercury, sets the latter free, phosphoric acid (PO_5) being produced. Some, by another metal, as when mercury is precipitated from a solution of its nitrate, by means of metallic copper, nitrate of copper being left in solution; or, when copper is thrown down, from a solution of one of its salts, by iron, which takes its place, and, forming a new salt, remains in the solution.

426. When an oxide is reduced, by heating it with fuel, the carbon, of the latter, unites with the oxygen of the former. If the oxide is in combination with carbonic acid, that acid must, first, be driven off, by heat: since carbon will effect the reduction only of an oxide. If a metallic salt is strongly heated, with carbon, the oxygen both of the acid and of base, is removed; and the elements, left behind, form a new combination:—in this way, sulphate forms sulphuret of lead. When a sulphuret is heated, in a current of air, the metal is oxidized: and both sulphurous, and sulphuric acid are produced:—a portion of the latter is driven off, and the remainder unites with an excess of

oxide. This process is termed "calcination."* If the residue were reduced by carbon, the result would be impure, on account of some sulphuret being formed, by deoxidation of the sulphuric acid. To prevent this, before deoxidation is begun, a proper amount of lime is added. The acid is taken away by the lime, which becomes, first a sulphate, then by the agency of the heat a sulphuret, and floats on the metal as a glassy scoria. Other circumstances, connected with this subject, shall be noticed, as I proceed.

427. Metallic oxides are divided into those of the metals proper, as the oxide of gold: those of the alkalies, as soda: of the alkaline earths, as lime: and of the earths proper, as alumina. All the earths, except silex, are metallic oxides.

428. The metals have been variously arranged. By some chemists, in two classes, as follow:—

- I. Those yielding alkalies, and earths. And
- II. Those yielding neither the one, nor the other.

CLASS I. CONTAINS

1. The bases of the alkalies.—Potassium, sodium, and lithium.
2. Bases of the alkaline earths.—Barium, calcium, magnesium, and strontium.
3. Bases of the earths.—Aluminum, glucinum, thorium, yttrium, and zirconium.

CLASS II. CONTAINS

1. Those which decompose water at a red heat.—Cadmium, cobalt, iron, manganese, nickel, tin and zinc.
2. Those which do not decompose water, at a red heat; and whose oxides are not reduced by heat alone.—Antimony, arsenic, bismuth, cerium, chromium, columbium, copper, lead, molybdenum, tellurium, titanium, tungsten, uranium, and vanadium.
3. Those which do not decompose water at a red heat; but whose oxides are reduced, at that temperature.—Gold, iridium, mercury, osmium, palladium, platinum, rhodium, and silver.

429. They have also been divided into six classes, according to their comportment with sulphuretted hydrogen, &c., as follow:—

CLASS I. CONTAINS

Those whose oxides are not precipitated by sulphuretted hydrogen, hydrosulphuret of ammonia, nor the alkaline carbonates.—Ammonium (?), potassium, sodium, and lithium.

* *Calx*, a cinder. *Lat.*

CLASS II. CONTAINS

Those whose oxides are not precipitated, by sulphuretted hydrogen; but are precipitated, by alkaline carbonates; and, under certain circumstances, as salts, by hydrosulphuret of ammonia.—Barium, calcium, magnesium, and strontium.

CLASS III. CONTAINS

Those whose oxides are not precipitated, by sulphuretted hydrogen; but are precipitated, as oxides, by hydrosulphuret of ammonia.—Aluminum, cerium, chromium, glucinum, tantalum, titanium, thorium, yttrium, and zirconium.

CLASS IV. CONTAINS

Those whose oxides are not precipitated, from their acid solutions, by sulphuretted hydrogen; but, are entirely precipitated, as sulphurets, by hydrosulphuret of ammonia.—Cobalt, iron (protoxide, and sesquioxide), manganese (protoxide), nickel, uranium, and zinc.

CLASS V. CONTAINS.

Those whose oxides are completely precipitated, from their solutions, whether acid alkaline or neutral, by sulphuretted hydrogen; their sulphurets being insoluble in alkaline hydrosulphurets.—Bismuth, cadmium, copper, lead, mercury, osmium, palladium, rhodium (sesquioxide), and silver.

CLASS VI. CONTAINS

Those whose oxides are completely precipitated, from their acid solutions, by sulphuretted hydrogen; but, since their sulphurets are soluble in alkaline hydrosulphurets, not from their alkaline solutions.—Antimony, arsenic, gold, iridium, molybdenum, platinum, selenium (?), tellurium, tin, tungsten, and vanadium.

We, however, shall find it more convenient to examine the metals in *alphabetical* order.—I shall notice, at the same time, a few of their more important compounds.

430. ALUMINUM:—*symb.* Al; *equiv.* 13·63. It was discovered by Wöhler, in 1828; and is obtained by acting, with potassium, on chloride of aluminum:—the chloride of potassium, which is formed, may be washed away, with water. A most intense heat is evolved; and the action is so violent, that it is not safe to carry on the process, in vessels of glass.

431. Aluminum, thus obtained, is in the form of brilliant grayish-coloured scales. Like iron, and iodine [361], when in a certain state of division, it does not conduct electricity: but,

* Thus named, because a constituent of alum $[(\text{SO}_3 + \text{KO}) + (3\text{SO}_3 + \text{Al}_2\text{O}_3)]$.

when fused, it is a conductor. It is ductile. It does not decompose water, at a temperature lower than 212° : and, at that point, but slowly. It dissolves rapidly in acids, and caustic alkalies; being changed into sesquioxide, and hydrogen, from the decomposed water, being evolved.

432. Aluminum forms, with oxygen, sesquioxide (Al_2O_3 ; 51·26), termed alumina. With chlorine, sesquichloride (Al_2Cl_3 ; 133·67). With sulphur, sesquisulphuret (Al_2S_3 ; 75·26). With phosphorus, sesquiphosphuret (Al_2P_3 ; 121·22). And, with selenium, sesquiselenuret (Al_2Se_3 ; 146·15), &c.

433. *Alumina* is the most remarkable of its compounds. It constitutes the chief parts of the ruby, and sapphire: and is an indispensable ingredient in every kind of earthenware [381]. It owes its ductility to, and has a strong affinity for water—which causes substances, containing much of it, to adhere to the tongue and lips. It has a powerful affinity, also, for colouring matter [139]; and for woody fibre. When breathed upon, it has a peculiar smell, termed “argillaceous.” This arises, partly from the presence of oxide of iron; and partly, perhaps, from its exhaling ammonia, which it has a great tendency to absorb. Pipe clay—which contains alumina—when moistened with caustic potash, will even after several days, emit enough ammonia to restore the colour of litmus paper, that has been reddened, by an acid.

434. Alumina is precipitated, from acids, as a hydrate ($Al_2O_3 + 3HO$), by the alkaline carbonates; and, by caustic potash, or soda—but it is redissolved, by excess of the alkali. It is precipitated, also, by ammonia, and redissolved by great excess. When alumina is thrown down, as a hydrate, it carries along with it, some of the substances, by which it is precipitated; and is not freed from them, except by repeated washing. It loses water, if exposed to a high temperature, and [heat 70°] contracts in bulk: but it becomes anhydrous, only at a white heat. Alumina is precipitated, as a white sulphuret, by hydrosulphuret of ammonia.

A mineral, containing alumina, when moistened with a minute quantity of the solution of nitrate of cobalt, acquires, before the blow-pipe, a beautiful blue colour.

435. ANTIMONY: *—*ymb.* Sb; *equiv.* 129·20. It was discovered by Basil Valentine, in 1490; and may be obtained, from sulphuret of antimony, one of its most abundant ores—the *stibium* of the ancients—by heating it with “black flux.”†

* From *anti*: and *moine*, a monk, *Fr.*—on account of the disagreeable effects, produced with it, on some monks, by its discoverer.

† Formed, by throwing into an ignited crucible—by small portions, at a time—a mixture, containing one part, by weight, nitre, and two parts cream of tartar (bitartrate of potash). The carbon of the resulting dark mass, when heated with metallic oxides, combines with their oxygen.

The potassium of the potash, combines with the sulphur of the sulphuret, forming sulphuret of potassium: and its oxygen unites, first with the antimony, forming oxide of that metal, and then with carbon, forming carbonic oxide. The fused metallic antimony falls to the bottom, and may be poured into moulds.

436. Antimony is white, but approaching to a bluish gray. Its specific gravity is 6.702. It is brittle. It fuses at 810° —or a little below redness; and is volatilized, by a white heat. It takes fire, spontaneously, in chlorine. It becomes tarnished, by exposure to the air; and is covered with a dark substance, by the continued action of air, and moisture.

437. Antimony forms, with oxygen, protoxide (SbO_3 ; 153.20); peroxide or antimonious acid (SbO_4 ; 161.20); and antimonie acid (SbO_5 ; 169.20). The latter, a yellow powder, is obtained, by acting on antimony with an excess of nitric acid, concentrating the solution—to drive off the excess of acid—and precipitating with water. It forms, with hydrogen, antimoniu-retted hydrogen (SbH_3 ; 132.20), which precipitates the salts of most metals—except those of copper, in which it differs from arseniu-retted hydrogen. Antimony forms, with chlorine, protochloride ($SbCl_3$; 235.61), formerly called “butter of antimony;” bichloride ($SbCl_4$; 271.08); and perchloride ($SbCl_5$; 306.55). With bromine, a bromide—not well known. With sulphur, protosulphuret (SbS_3 ; 177.2); sulpho-antimonious acid (SbS_4 ; 193.2); and sulpho-antimonie acid (SbS_5 ; 209.2), &c.

The oxide and protochloride form oxy-chloride—called, from the name of its discoverer, “the powder of Algarotti.” It is obtained, by adding a considerable quantity of water to the chloride. Both are decomposed, and hydrochloric acid is set free. $4SbCl_3 + 9HO = (SbCl_3 + 3SbO_3 + 3Aq) + 9HCl$. It becomes heavy and crystalline, after some time: but immediately, when the water employed is hot.—If tartaric acid is present, or is added, the precipitate dissolves: which is not the case with the analogous precipitate formed by bismuth. The oxide, and protosulphuret, form oxy-sulphuret ($2SbS_3 + SbO_3$).

438. Antimony, in solution as protoxide, gives, with caustic potash, the alkaline carbonates, phosphate of soda, and with ammonia, a white precipitate—the oxide itself, soluble in caustic potash. With sulphuretted hydrogen, in acid solutions, and hydrosulphuret of ammonia, in all, an orange yellow precipitate—the hydrated protosulphuret, which is soluble in excess, in caustic potash, and in hydrochloric acid: and is distinguished from orpiment (AsS_3), by not being volatile: and from bisulphuret of tin, by forming, along with zinc and sulphuric acid, antimoniu-retted hydrogen. If the glass tube through which this gas is transmitted is ignited, the antimony will be reduced at the heated part, and will exhibit a brilliant appearance; but, on

passing dry sulphuretted hydrogen through the tube, it will become a yellow sulphuret: and the latter will be changed, by hydrochloric acid gas, into volatile chloride—which, being received into water acidulated with hydrochloric acid, may be precipitated with sulphuretted hydrogen. Metallic zinc throws down antimony, as a black powder—and along with it, if nitric acid is present, some sesquioxide.

439. ARSENIC: *—*symb.* As; *equiv.* 74·92. This metal was discovered by Brandt in 1733. It is found in nature, combined with other metals: and is generally procured, in roasting the ores of cobalt, and nickel. The arsenious acid, carried into the chamber intended for its reception, is purified by re-sublimation; and metallic arsenic is obtained from it, by heating it to redness, in a crucible, along with twice its weight of black flux [435]. The metal sublimes into a larger crucible, inverted for the purpose over the former, and is condensed in it.

440. Arsenic is white, but approaching to a steel gray colour. Its specific gravity is 5·8843. It is extremely brittle: and it crystallizes in rhombohedrons [65]. It sublimes, without melting, at 356°; and its vapour has the smell of garlic. It is supposed, by Regnault, to be incapable of assuming the fluid state, on account of the point at which it boils under the pressure of the atmosphere being very near that at which it fuses. As the point at which bodies liquefy is not affected by pressure, while that at which they boil is, increasing the pressure sufficiently would probably render arsenic fusible. By the action of the air, it gradually changes to a gray powder—the suboxide, supposed by some, to be a mixture of arsenious acid and metallic arsenic. It is rapidly oxidated, in nitric acid; it deflagrates, violently, in melted nitre; and burns spontaneously, with a beautiful blue flame, in chlorine.

441. Arsenic forms, with oxygen, arsenious acid (AsO_3 ; 98·92), called, “white arsenic,” and “oxide of arsenic;” also arsenic acid (AsO_5 ; 114·92). With hydrogen, protohydruret (AsH ; 75·92) supposed to be metallic arsenic, in a finely divided state; and arseniuretted hydrogen (AsH_3 ; 77·92). With chlorine, chloride (AsCl_3 ; 181·33). With iodine, periodide (AsI_3 ; 709·17). With bromine, bromide (AsBr_3 ; 314·83). With sulphur, bisulphuret (AsS_2 ; 90·92), called, also, “realgar;” sulph-arsenious acid (As_3 ; 122·92) [292], termed “yellow arsenic,” and “orpiment;” and persulphuret (AsS_5 ; 154·92), or sulph-arsenic acid, &c.

442. Arsenic, in solution, gives, with sulphuretted hydrogen, and hydrosulphuret of ammonia, a yellow precipitate—sulph-arsenious, or sulph-arsenic acid. It may be easily distinguished, from the sulphurets of selenium, cadmium, tin, or antimony: for, when ignited, with twice its weight of black flux, in a hard

* *Arsenicus*, powerful. *Gr.*; from its poisonous properties.

glass tube, metallic arsenic sublimes into the *upper* part: and there is a smell of garlic, from some oxide being formed. Before testing, the solution must be rendered acid, by adding acetic, or hydrochloric acid, since the precipitate would be redissolved by free alkali. Nitrate of silver causes, in neutral, and ammonio-nitrate ($\text{NO}_3 + \text{AgO} + 2\text{NH}_3$), in acid solutions, a yellow precipitate ($\text{AsO}_3 + 3\text{AgO}$, or $\text{AsO}_3 + 3\text{AgO}$), soluble in dilute nitric acid, and in water of ammonia. Sulphate of copper produces in neutral, and ammonio-sulphate [$(\text{SO}_3 + \text{NH}_3\text{O}) + (\text{NH}_3\text{CuO})$], in acid solutions, a yellowish green ($\text{AsO}_3 + 2\text{CuO}$), or a greenish blue ($\text{AsO}_3 + 2\text{CuO} + \text{HO}$) precipitate. Lime water, and the soluble salts of lime, give, with arsenious acid, a white arsenite ($\text{AsO}_3 + 2\text{CaO}$).

443. Arsenic may be detected, likewise, by filtering the liquor supposed to contain it, acidulating it with sulphuric acid, and placing it in a flask, to which a small tube of hard glass has been attached. On introducing into the acidulated liquor, a piece of zinc, if arsenic is present, arseniuretted hydrogen will be evolved: and, when set on fire, will deposit metallic arsenic on a bit of glass tube, held over the flame. If the gas is produced, only in minute quantities, a part of the hard glass tube, through which it passes, is to be ignited: and the metallic arsenic will be deposited, *beyond* the heated portion. Arseniuretted hydrogen, may be distinguished from antimoniuiretted, by the part of the ignited tube, in which the metal is deposited.—Besides, arsenic is volatilized by heat, which is not the case with antimony. If the suspected fluid contains both antimony and arsenic, they will be deposited in their respective portions of the tube—one at the heated part [438], and the other beyond it. Zinc, and sulphuric acid, sometimes contain arsenic: and it has been found in the human body, without having been administered as a poison. Hydrated peroxide of iron is an antidote for arsenic:—the resulting arsenite of iron is not poisonous.

444. BARIUM: *—*symb.* Ba; *equiv.* 68.39. It was discovered by Davy in 1807: and is conveniently obtained from nitrate of barytes. When the latter is gently heated to redness, in a porcelain crucible, it melts, and is decomposed—the nitric acid giving off, in succession, each atom of its oxygen. When it has become nitrous oxide, it combines with the barytes; but the resulting compound is decomposed, the last atom of oxygen—as also the nitrogen—being evolved, and pure barytes being left behind. To prevent the inconvenience, arising from the frothing up of the decomposing salt, the nitrate may be previously mixed with twice its weight of sulphate of barytes, in fine

* *Barūs*, heavy. *Gr.* Because sulphate of barytes, on account of its great weight, was termed “heavy spar.”

powder; and, after the process is finished, the barytes may be dissolved out, with hot water, from the sulphate—which is not changed. If the vapour of potassium is passed over the barytes, heated to redness, potash will be formed, and metallic barium will be set free. The latter may be dissolved out by mercury, and the mercury driven off, by heat.

445. Barium is of a grayish white colour; it is heavier than oil of vitriol. It fuses below a red heat: decomposes water rapidly—hydrogen being liberated, and oxide of barium being left in solution.

446. Barium forms, with oxygen, protoxide (BaO ; 76·39), called also “baryta,” and “barytes;” and peroxide (BaO_2 ; 84·39). With chlorine, chloride ($BaCl$; 103·86). With iodine, iodide (BaI ; 195·24). With bromine, bromide ($BaBr$; 148·36). With fluorine, fluoride (BaF ; 87·25). With sulphur, sulphuret (BaS ; 84·39), &c.

447. *Barytes* (BaO) may be obtained, by gently heating nitrate of barytes to redness in a porcelain crucible, until the escape of gas has ceased. To prevent inconvenience from frothing, the nitrate may be mixed previously with twice its weight of sulphate of barytes in fine powder: and after the process the resulting barytes may be dissolved out from the insoluble sulphate, by boiling with water.

448. *Nitrate of barytes* ($NO_3 + BaO$) may be formed from native carbonate, by digesting with dilute nitric acid, and filtering the solution. The crystals obtained from the latter are purified by recrystallization.

449. *Chlorate of barytes* ($ClO_3 + BaO$) may be made, by passing chlorine, through a solution of barytes in hot water: which produces chloride of barium and chlorate of barytes. The chloride of barium is decomposed by nitrate of silver, which throws down chloride of silver, that may be removed by decantation, and leaves nitrate of barytes in the solution—from which chlorate of barytes may be precipitated if the liquor is concentrated by evaporation.

450. *Chloride of barium* ($BaCl$) may be obtained, by dissolving the native carbonate in dilute hydrochloric acid. Carbonic acid is evolved; and chloride of barium crystallizes from the hot solution in rhomboidal tables. This chloride precipitates carbonic, hyposulphurous, sulphurous, hyposulphuric, sulphuric, selenic, hypophosphorous, phosphorous, phosphoric, boracic, silicic, and hydrofluoric acids; also many metallic acids, from their neutral solutions.

451. Barytes gives, with carbonate of soda, a white carbonate ($CO_2 + BaO$); with sulphuric acid, or a soluble sulphate, a white sulphate ($SO_3 + BaO$)—insoluble in nitric, or hydrochloric acid; and with hydrofluosilicic acid, a white silicofluoride

of barium ($\text{SiF}_6 + \text{BaF}$). None of these precipitates are affected, by water containing sulphuretted hydrogen.

452. The soluble combinations of barium are all poisonous: and the carbonate becomes so, on account of meeting, in the stomach, with hydrochloric acid, which changes it into a soluble compound. From this cause, fowl will not live where it is found among the gravel, &c.—on account of their habit of swallowing small pebbles, to aid the gizzard in triturating their food.

453. BISMUTH: *—*symb.* Bi; *equiv.* 70·95. This metal was known to the ancients; and was described by Agricola, in 1530. It is obtained from the rocks, in which it is found, by pounding to a coarse powder, and igniting them:—the bismuth melts out.

454. Bismuth is white, with a shade of red; and has a crystalline structure. Its specific gravity is 9·822. It is brittle, when cold; but it may be hammered into plates, when warm. It melts at 497° —or below redness. When heated to whiteness, it is volatile, and burns, the flame being of a bluish white. It is little affected, by exposure to the air, at common temperatures:—it is, however, easily oxidated. Nitric acid acts upon it, with great energy; but it is scarcely affected by sulphuric, or hydrochloric acid. It may be purified, by deflagrating some nitre upon it, when it is in a state of fusion: for its impurities, being more oxidizable than itself, float, as scoria, on its surface.

455. Bismuth forms, with oxygen, protoxide (BiO_3 ; 94·95), formerly called “magistery of bismuth;” peroxide (BiO_4 ; 102·95); and superoxide (BiO_5 ; 110·95), or “bismuthic acid.” With chlorine, chloride (BiCl_3 ; 177·36), formerly called “butter of bismuth.” With bromine, bromide (BiBr_3 ; 310·86). With sulphur, sulphuret (BiS_3 ; 118·95), &c.

The chloride of bismuth, like that of antimony [437], affords an oxychloride ($\text{BiCl}_3 + 2\text{BiO}_3 + 3\text{Ag}$) if water is added to it.—Water is decomposed, and hydrochloric acid set free. This basic chloride is called “Spanish white,” and “pearl white.” It may be distinguished from the corresponding salt of antimony by being insoluble in tartaric acid.

456. Solutions of bismuth give, with the caustic alkalies, a white hydrated oxide ($\text{BiO}_3 + \text{HO}$); and with the alkaline carbonates, a bulky white basic carbonate ($\text{CO}_2 + \text{BiO}_3$). When carbonate of potash is used, some of it is carried down with the precipitate, and cannot be easily separated: when carbonate of soda, all the bismuth is not precipitated. Sulphuretted hydrogen, or hydrosulphuret of ammonia, throws down from neutral, or acid solutions, a black sulphuret (BiS_3), soluble in boiling nitric acid. This precipitate is not formed when an excess of hydrochloric, or nitric acid is present, unless water is

* *Weismuth*, white mother of silver. *Ger.*

added. Chromate of potash gives a yellow chromate ($\text{CrO}_3 + \text{BiO}_3$), differing from chromate of lead, by being soluble in dilute nitric acid, but insoluble in potash. Ferrocyanide of potassium gives a white, and ferridcyanide, a yellow precipitate.

457. CADMIUM : *—*ymb.* Cd .; *equiv.* 55·74. It was discovered by Stromeyer, in 1818. It is a very rare metal: and is obtained from the ores of zinc, with which it is associated. Dr. Wollaston separated it from the other metals, which are found along with it, by dissolving them: then placing the solution in a platinum vessel, and immersing in it, a piece of zinc.—The cadmium is reduced, and adheres so strongly to the platinum, that it may be washed with water, without separating. It is dissolved off, with dilute nitric acid: the nitrate is ignited: and the resulting oxide of cadmium (CdO) is exposed to a high temperature, in contact with carbon. Metallic cadmium passes over, in vapour.

458. Cadmium is white; its specific gravity is 8·69. It melts, at about 442° —or below redness. It dissolves, slowly, in dilute sulphuric: but, rapidly, in dilute nitric acid.

459. Cadmium forms, with oxygen, oxide (CdO ; 63·74). With chlorine, chloride (CdCl .; 91·21). With iodine, iodide (Cd.I ; 182·59). With sulphur, sulphuret (Cd.S ; 71·74), &c.

460. Cadmium gives, with potash, and, with ammonia, a white precipitate, the hydrated oxide ($\text{CdO} + \text{HO}$), soluble in ammonia; and, with the alkaline carbonates, a white carbonate ($\text{CO}_2 + \text{CdO}$). Carbonate of ammonia must not be used, as the presence of ammoniacal salts, prevents the complete precipitation of cadmium, by a carbonate. Sulphuretted hydrogen, and hydrosulphuret of ammonia, throw down a bright yellow sulphuret (CdS), which is decomposed, and dissolved by boiling concentrated nitric acid. In solutions, containing a considerable quantity of free acid, it is necessary to add water—in order to throw down the cadmium, with sulphuretted hydrogen. Metallic zinc precipitates cadmium, in the metallic state, as gray spangles.

461. CALCIUM : †—*ymb.* Ca ; *equiv.* 20·0. It was discovered by Davy, in 1807; and is obtained from lime, in the same way as barium, from barytes [444]. It is white metal, heavier than water—which it decomposes rapidly, lime (CaO) being produced, and hydrogen evolved.

462. Calcium forms, with oxygen, oxide (CaO ; 28·0), called “lime,” and “quick lime;” also peroxide (CaO_2 ; 36·0). With chlorine, chloride (CaCl ; 55·47). With iodine, iodide (CaI ; 146·85). With bromine, bromide (CaBr ; 99·97). With sul-

* *Cadmia*, a name, given in commerce, to the volatile matters, which rise from the surface, when brass is made.

† From *Calx*, lime, *Lat.* :—because lime is an oxide of that metal.

phur, sulphuret (CaS ; 36); bisulphuret (CaS_2 ; 52), and pentasulphuret (CaS_5 ; 100). With phosphorus, phosphuret (CaP ; 51·32). With fluorine, fluoride (CaF ; 38·86), found in nature, as "Derbyshire spar," &c.

463. *Lime* is the most remarkable of the compounds of calcium; and also, the most interesting, and important of the earths. It is obtained, by calcining a carbonate—which, for the purposes of the laboratory, may be white marble. The heat drives off the carbonic acid. It has a very strong affinity for water [35]:—when exposed to the air, it takes moisture gradually, from the atmosphere, and falls into a powder, which is a hydrate ($\text{CaO} + \text{HO}$). If dry, it has hardly any tendency to absorb carbonic acid; but, as a hydrate, a very strong one—the water being expelled by the acid. When the lime is half saturated, the carbonic acid is taken up by it, with less rapidity.

464. *Carbonate of lime* ($\text{CO}_2 + \text{CaO}$). Lime is very abundant, as a carbonate:—it constitutes enormous masses of limestone, chalk, and marble. It occurs, also, in the bones, teeth, and shells of animals, &c.—All of it has, probably, had an animal origin. Its production, from shells, can often be clearly perceived, in some kinds of limestone, and marble.—The latter differs from the former, &c., merely, in having been subjected to volcanic heat, under such pressure as prevented the carbonic acid from being driven off, at a temperature sufficient to melt the carbonate. It was known, long since, that carbonate of lime is capable of fusion, without being decomposed: for, in some of the ancient churches of England, marble pillars are found, which were evidently cast—the marks, arising from the different portions of the mould having been carelessly put together, being distinctly visible. But, the mode of casting marble was forgotten for ages: and even the possibility of fusing it was denied, notwithstanding the testimony of these pillars. The method has been, however, rediscovered—though, as far as I am able to learn, it is not at present used. Chalk is, probably, nothing more than carbonate of lime, precipitated from its solution in water containing carbonic acid.—Whether the carbonic acid merely gives to that fluid a solvent power, which it does not possess without it, or the lime becomes a bicarbonate, has not been agreed upon by chemists:—those who hold the latter opinion, are most probably right.

465. *Sulphate of lime* ($\text{SO}_3 + \text{CaO}$) may be obtained, by adding chloride of calcium to dilute sulphuric acid, and washing the precipitate well with water. It is found in nature, as "alabaster," ($\text{SO}_3 + \text{CaO} + 2\text{HO}$), and "gypsum"—from which, by calcination, is obtained "plaster of Paris." The latter is very important, on account of combining rapidly with water—so as

to form a hard, and solid compound. If the gypsum, during calcination, is exposed to a higher temperature than 300° , the sulphate which results, will not unite with that fluid; and is found in nature, as “anhydrite.”

466. *Basic tribasic phosphate of lime* ($3\text{PO}_5 + 8\text{CaO}$), or the *earth of bones*, consists, probably, of two phosphates [$2(\text{PO}_5 + 3\text{CaO}) + (\text{PO}_5 + 2\text{CaO} + \text{HO})$]. It is found, associated with fluoride of calcium, in bones, teeth, &c.; and may be obtained, by neutralizing the solution of any phosphate of lime with ammonia.

A brown mass, consisting of a phosphate of lime, and phosphuret of calcium is produced, when vapour of phosphorus is passed through a red hot tube, containing lime:—if this is thrown into water, the latter and the phosphuret, mutually decompose each other—phosphuretted hydrogen, which [325] in flames on reaching the surface of the fluid, and phosphite of lime being formed.

467. *Chloride of calcium* (CaCl) may be obtained, by dissolving white marble, or any pure carbonate of lime, in dilute hydrochloric acid. The solution should not have an acid reaction.

468. Sulphuric acid, and the soluble sulphates produce immediately, in concentrated solutions of the salts of calcium, white precipitates ($\text{SO}_3 + \text{CaO}$):—if the solutions are more dilute, the precipitate forms but slowly: and if very dilute, not at all, the resulting sulphate of lime being held in solution—unless alcohol is added. Oxalic acid gives, with salts of calcium, a white oxalate ($\text{O} + \text{CaO}$), slightly soluble, in excess;—ammonia increases the facility of precipitation, and the amount of precipitate. The oxalate, and phosphate of lime are dissolved, unchanged, by hydrochloric acid, and will be obtained again by adding ammonia. Hence, if free hydrochloric acid is present, in sufficient quantity, oxalic acid may give no precipitate, with lime.

The soluble salts of calcium give to alcohol, a yellowish red flame, like those of strontia; but may be distinguished, from the latter, by tinging the flame of the blow-pipe a brick colour.

469. CERIUM; *—*symb.* Ce; *equiv.* 46.05. This metal was discovered by Husinger, and Berzelius, in 1804: and is found in “cerite,” a rare mineral. It may be obtained, by calcining that substance, pulverizing, and dissolving it in aqua regia: then neutralizing the solution, with caustic potash, precipitating oxide of cerium, with tartrate of potash, changing the oxide to sulphuret—by heating it to redness, for half an hour, along with three times its weight of sulphuret of potassium: and, finally, converting the sulphuret into protochloride, by passing chlorine

* From the planet Ceres.—It will be seen that the discoverers of certain metals, have given to them, inappropriate and, sometimes, very whimsical names.

over it when raised to a high temperature in a glass tube, and, while the tube is hot, carrying off the volatile matters, by a current of hydrogen. Pieces of potassium are, after this, introduced into the tube, and heat is again applied:—the vapour of potassium, as it passes over the chloride, reduces some of it. The residue is then washed with alcohol, of a specific gravity 0·85, to remove the chloride of potassium, which has been formed. The brown powder that is left, and which consists of cerium, some of its oxide formed by the alcohol, &c., is to be pressed between the folds of blotting paper, and dried in vacuo.

470. The pure metal, which was obtained by Vanquelin, in very minute quantities, is white, and brittle. It resists the action of nitric, but is dissolved by hydrochloric acid.

It forms, with oxygen, protoxide (CeO ; 54·05); and peroxide (Ce_2O_3 ; 116·10). With chlorine, protochloride (CeCl ; 81·52); and perchloride (Ce_2Cl_3 ; 198·51). With sulphur, protosulphuret (CeS ; 62·05), &c.

471. The salts of cerium have a sweet taste. They give, with potash and ammonia, yellowish white precipitates, that become yellow by exposure to the air. They give no precipitate, with sulphuretted hydrogen; but white ones, with sulphuret of potassium, ferrocyanide of potassium, and oxalate of ammonia.

The discovery of lanthanum, and didimium—which are always found along with cerium—has rendered the received equivalent of the latter, doubtful.

472. CHROMIUM: *— *symb. Cr.; equiv. 27·99.* It was discovered by Vanquelin, in 1797: and is found, combined with lead or copper, as chromic acid; but, more abundantly, in chrome iron ore ($\text{Cr}_2\text{O}_3 + \text{FeO}$), as chromic oxide. To obtain it, the chrome iron ore is heated to redness with nitrate of potash, and the resulting chromate of potash, being dissolved out with water and filtered, is neutralized with nitric acid, and evaporated:—the salt it contains is then removed, by crystallization. A solution of the crystals, in water, being added to a solution of neutral nitrate of mercury, red chromate of mercury is precipitated. The mercury, and half the oxygen of the chromic acid, being expelled by a red heat, sesquioxide of chrome is left behind. Metallic chromium is obtained from this, by heating it intensely, in a crucible lined with charcoal, along with a mixture of plumbago and oil.

473. Chromium is a grayish white metal. Its specific gravity is 5·9, or 6·0. It is brittle: and very infusible—being melted by a heat, but little less than that of the oxy-hydrogen blow-pipe. It is scarcely affected, by acids, except the hydrofluoric,

* *Chrōma*, colour, *Gr.*:—from its tendency to form coloured compounds.

in which it dissolves, hydrogen being evolved:—it is very slightly soluble, even in aqua regia.

474. Chromium forms, with oxygen, protoxide (CrO ; 35·99); sesquioxide (Cr_2O_3 ; 79·98), the “green oxide;” chromic acid (CrO_3 ; 51·99). This compound, when strongly heated, gives off half its oxygen, and becomes oxide.—It oxidizes organic substances, powerfully: and is, therefore, used in analyses. It is employed, also, in bleaching. Chromium forms, with oxygen, likewise, perchromic acid (Cr_2O_7 ; 111·98). With chlorine, chloride (CrCl ; 63·46): sesquichloride (Cr_2Cl_3 ; 162·39). With fluorine, sesquifluoride (Cr_2F_3 ; 112·56), &c. It forms an oxychloride ($\text{CrCl}_3 + 2\text{CrO}_3$), called chlorochromic acid, &c.

475. Sesquioxide of chromium is remarkable for existing, in two states, each of which has its own salts.—As a hydrate ($\text{Cr}_2\text{O}_3 + 5\text{HO}$), which is soluble, though slowly, in dilute acids, and is of a bluish gray colour; and anhydrous, being then insoluble in dilute acids, but soluble slowly, in boiling concentrated sulphuric acid. The salts of the hydrated oxide are green. They are soluble in hydrochloric acid; and, some of them in water—the solutions, even when very dilute, being of a blackish green, and reddening litmus paper. The salts of the anhydrous oxide, are of a bright violet colour; and are insoluble, in water, or the acids. Heat changes the soluble oxide, into the insoluble: and many of its salts, into those of the insoluble, their colour being altered from green to violet. On the other hand, fluxing what have been thus altered, with carbonate of soda, reconverts them into those of the soluble oxide.

476. Sesquioxide of chromium is precipitated from its combinations, as a bluish green hydrate ($\text{Cr}_2\text{O}_3 + \text{HO}$), by caustic potash, and is redissolved by excess—the solution being emerald green; but, it is reprecipitated, by long continued boiling, or, by the addition of sal-ammoniac. The same precipitate is thrown down, by ammonia, and a small part of it is redissolved by excess, the solution being of a peach blossom red colour:—the application of heat, reprecipitates what was redissolved.

477. Chromic acid gives, with the salts of lead, a yellow chromate ($\text{CrO}_3 + \text{PbO}$), soluble in caustic potash, and changed to red, when heated with ammonia. And, with the salts of the black oxide of mercury, an orange precipitate ($\text{CrO}_3 + \text{Hg}_2\text{O}$).—When this, which is the subchromate, is heated to redness, mercury and oxygen are driven off, and sesquioxide is left behind [472]. It gives with chloride of barium, a yellowish white chromate of barytes ($\text{CrO}_3 + \text{BaO}$), soluble in dilute hydrochloric, and nitric acid. With nitrate of silver, a dark purple red chromate ($\text{CrO}_3 + \text{AgO}$), soluble in nitric acid, and ammonia. With ferrocyanide of potassium, a grayish green precipitate. Chromic acid,

whether in the free state, or combined, forms with sulphuretted hydrogen, oxide of chromium sulphuric acid and water being produced, sulphur being precipitated, and the solution being changed to green. When no free acid is present, some hydrated oxide of chromium is thrown down, also—the precipitate being then greenish gray. Chromic acid imparts a beautiful green, to glass.

478. COBALT :*—*ymb. Co; equiv. 29.48.* It was discovered by Brandt, in 1773; and is found in combination with arsenic, sulphur, and nickel. It resembles the latter, very much, in its properties; and is entirely separated from it, with great difficulty. Cobalt is obtained from the native arseniuret.—For this purpose, the ore is roasted in a current of air, to oxidize both the cobalt and the arsenic: the result, which constitutes the “zaffre” of commerce, is dissolved in hydrochloric acid: and sulphuretted hydrogen is passed through the solution, to precipitate the arsenic, and, along with it, any copper present. The precipitate having been removed, the clear liquor is to be boiled with a little nitric acid, to peroxidate the iron—which, along with the cobalt, is precipitated by carbonate of potash; and the mixed precipitate being digested with oxalic acid, soluble oxalate of iron, and insoluble oxalate of cobalt are formed. The latter being removed, it is best freed from the nickel it still contains, by the process of Liebig, which is as follows.—Much more hydrochloric acid is added than is sufficient to dissolve the oxalate, and more than enough cyanide of potassium, than is required to redissolve the precipitate first formed; after which, a little hydrochloric acid being dropped in, now and then, but not enough to produce an acid reaction, the solution is kept boiling for some time in a flask held obliquely, until the hydrochloric acid no longer causes the odour of hydrocyanic acid to be perceptible. An excess of caustic potash is then added, and, the mixture having been boiled for about ten minutes, the precipitated protoxide of nickel is removed. The filtered liquor is evaporated to dryness, with excess of nitric acid, and fused: the residual peroxide of cobalt is washed with water, dissolved in hydrochloric acid, and precipitated again, as oxalate. Oxalate of cobalt being ignited, carbonic acid is evolved, and spongy metallic cobalt remains behind.

479. The above process is easily explained.—When cyanide of potassium is added to the solution of nickel, &c., cyanide of nickel (NiCy) is precipitated: and, being redissolved, by excess of cyanide, forms double cyanide of nickel and potassium

* *Kobold*, an evil spirit, *Ger.* This name was given to it, by the German miners, who did not know its value: and thought it unfavourable in the presence of the other metals.

($\text{NiCy} + \text{KCy}$). Since the solution contains cobalt, along with free hydrochloric acid, cyanide of cobalt (CoCy) is produced, and being redissolved, becomes cobalti-cyanide of potassium ($\text{Co}_2\text{Cy}_6\text{K}_3$): which, if three atoms of nickel are present, for every two of cobalt, is changed into cobalti-cyanide of nickel ($\text{Co}_2\text{Cy}_6\text{Ni}_3$), thrown down, in the form of a bluish white precipitate. If there is *less* than that proportion of nickel, some cobalti-cyanide of potassium remains undecomposed, and in solution: if there is *more*, some double cyanide of nickel and potassium, remains undecomposed—until, being boiled with hydrochloric acid, it is changed into chloride of nickel, and chloride of potassium.

When the caustic potash is added in excess, the cobalti-cyanide of nickel is decomposed, cobalti-cyanide of potassium being reproduced, and protoxide of nickel precipitated. $\text{Co}_2\text{Cy}_6\text{Ni}_3 + 3\text{KO} = \text{Co}_2\text{Cy}_6\text{K}_3 + 3\text{NiO}$.

When the filtered liquor is evaporated with nitric acid, the salts it contained are changed into nitrates: and the nitrate of cobalt is decomposed, by fusion, peroxide of cobalt being left behind.

480. Cobalt is of a reddish gray colour; its specific gravity is 8.538. When quite pure, it is not magnetic. It melts more easily than cast iron. It is not affected so much by water, and the acids, as iron, and zinc—but more than nickel.

481. Cobalt forms, with oxygen, protoxide (CoO ; 37.48); sesquioxide (Co_2O_3 ; 82.96); one complex oxide (Co_3O_4 , equivalent to an atom of oxide, and an atom of sesquioxide; 120.44); and another (Co_6O_7 , equivalent to four atoms of protoxide, and one of sesquioxide; 232.88). With chlorine, chloride (CoCl ; 64.95). With sulphur, sulphuret (CoS ; 45.48).

The solution of chloride of cobalt is pinkish—unless it contains nickel, in which case it will be green. The pure chloride, when dried, is blue: and is used to produce blue “sympathetic ink”—which becomes visible, on being heated. If the chloride contains nickel, it becomes green, on being heated: and is the substance employed in producing the representation of a winter and a summer scene, by means of the same picture.—When the winter landscape is heated, the grass, &c., immediately becomes green.

482. Cobalt, in solution, is known, by giving, with caustic potash, a blue precipitate. The latter is a basic salt, which is changed by boiling with excess of potash, air being excluded, into a bright red hydrated protoxide ($\text{CoO} + \text{HO}$), soluble in carbonate of ammonia: but, boiled in contact with air, it becomes a dingy red mixture, consisting of hydrated protoxide, with some peroxide formed during the process. If the protoxide is ignited, in atmospheric air, it becomes one of the hydrated complex oxides.

Ammonia gives the same blue precipitate—which is soluble in excess of the precipitant, and forms a solution, that is at first green, but is changed by the air, to brown. Neither potash nor ammonia, cause a precipitate, if there is much sal-ammoniac present; but the solution becomes brown, by the action of the atmosphere. The alkaline carbonates give, with solutions of cobalt, a red which, being boiled, becomes a blue precipitate. Phosphate of soda, gives a blue precipitate. Sulphuretted hydrogen, in alkaline solutions of the protosalts, and hydrosulphuret of ammonia, in neutral solutions, give a black sulphuret (CoS):—in other cases there is partial precipitation. Cyanide of potassium, gives a brownish white cyanide—redissolved by excess, and not reprecipitated by acids: ferrocyanide of potassium, a green precipitate, which gradually turns to gray: ferridcyanide of potassium, a brown precipitate.

483. The smallest quantity of cobalt colours glass blue, before the blow-pipe. *Smalt*, a glass stained with cobalt, and ground extremely fine, is used for colouring porcelain, &c., and giving a slight shade to paper, linen, &c. When quite pure it is a silicate of cobalt.—The silex it contains causes paper tinted with it to wear the nibs of pens rapidly. Chlorine, or oxygen, injures the colour produced by cobalt.

484. COLUMBIUM: *—*ymb.* Ta ; † *equiv.* 184·90. It is called, also, *tantalum*: and was discovered by Hatchett, in 1802. It is a very rare metal: and is obtained, by a process similar to that used for procuring silicon [373]—which it resembles very much.

485. Columbium is a black powder, that becomes, under the burnisher, an iron gray. In the pulverulent state [elect. 20], it is a non-conductor of electricity. It burns vividly, when heated in the air; but does not melt, at a lower temperature than that produced by the oxy-hydrogen blow-pipe. It is acted upon, only by hydrofluoric acid.

486. Columbium forms, with oxygen, binoxide (TaO_2 ; 200·90); and columbic or tantalic acid (TaO_3 ; 208·90), which, if hydrated, a milk white, insipid, inodorous powder. With chlorine, trichloride (TaCl_3 ; 291·31), &c.

487. Tantallic acid is separated from its solutions in the other acids, by sulphuric acid. It is thrown down, from its solution in hydrochloric acid, by tincture of galls, as an orange yellow powder: and is precipitated, unaltered, by the alkaline hydrosulphurets—sulphuretted hydrogen being evolved. It

* From Columbia, in America:—on account of being first found, in a black mineral, supposed to have been brought from North America.

† Two years after the discovery of columbium, Ekeberg, a Swedish chemist, obtained a metal, which he called tantalum:—but it was proved identical with columbium, to which it gave a symbol.

gives, with ferrocyanide and sulphocyanide of potassium, white precipitates. It is soluble in caustic alkalies; and in the alkaline carbonates, at a boiling temperature—carbonic acid being liberated. When heated it becomes anhydrous, and, while hot, is yellow, but, when cold, white:—in this state, it dissolves with difficulty, in acids and alkalies. When tantalic acid is precipitated by sulphuric acid, and brought into contact with zinc and hydrochloric acid, it dissolves—the solution being, at first blue, but afterwards brown. If the solution of a tantalate is acidified by hydrochloric acid, metallic zinc throws down from it a white tantalate.

Tantalac is distinguished from titanic acid, by the ease with which it is soluble in caustic potash.

488. COPPER:—*symb.* Cu; * *equiv.* 31·68. It was well known to the ancients: and is found in abundance—often native, and, not unfrequently, crystallized. It is most commonly obtained as a native sulphuret:—copper pyrites ($\text{Cu}_2\text{S} + \text{Fe}_2\text{S}_3$) generally affords the copper of commerce. Since two metals are contained in this ore, and neither is volatile, it is necessary, in order to obtain one of them free from the other—besides the ordinary means for reducing sulphurets—to use certain precautions in the method employed. That the copper may not, during its reduction, be rendered impure, by the presence of iron, the process is stopped before that metal is reduced. But, as the reduction cannot be made to terminate, precisely at the proper moment, the resulting copper still contains some iron, and sulphur. It is calcined, to separate it from these—which, being more combustible than the copper, are first oxidized: and the separation is facilitated by sand—which forms silicate of iron. If the copper is kept too long in contact with the fuel, some of it combines with carbon; if it is not kept sufficiently long, it will contain suboxide:—and, in either case, it will be brittle, and unfit for many of the purposes to which it is to be applied.

489. Copper is obtained, also, in the metallic state, by precipitating it with iron, from its salts—held in solution by the water that runs from copper mines, &c. For this purpose, old iron is thrown into the liquid, and takes the place of the copper, which is set free.

490. Copper is of a reddish colour. The crystals which it forms when fused or precipitated, are not the same as those found native. Its specific gravity is 8·9. It is very malleable, and ductile; and is the strongest of all the metals [mech. 31] except iron. It is an excellent conductor of heat, and of electricity. It melts at 1996° : and is not volatilized, by heat. It

* From *cuprum*, its Latin name—derived from that of the island of Cyprus, whence, anciently, it was obtained.

is not affected by dry air; but in moist, it is gradually covered with a greenish hydrated basic carbonate $[(\text{CO}_2 + \text{CuO}) + (\text{CuO} + \text{HO})]$ which, though very thin, preserves the metal under it. Acids that, like the nitric, give off oxygen directly, dissolve copper [218]. The others, even including carbonic, dissolve it where it is in contact with the atmosphere—by which it is oxidized. In this way poisonous salts are produced, in culinary vessels, by the carbonic, acetic, and the fatty acids. Water strongly impregnated with sulphuretted hydrogen is an antidote for the salts of copper: also large doses of sugar. Sulphuric acid, at a boiling temperature [306], dissolves copper—sulphurous acid being given off. Sometimes, when it is dissolved in nitric acid, a portion falls down, as oxide. If a red hot copper wire is drawn through cork, it will be rendered beautifully clean—the oxide which soiled it, having been reduced by the carbon; but it will be immediately tarnished again, by the air—oxide being reproduced.

491. Copper forms, with oxygen, red or suboxide Cu_2O ; 71·36).—When copper is coated with this, either naturally, or artificially, it has but little tendency to rust. It forms, also, black or protoxide (CuO ; 39·68), called by the mineralogists, “copper black.” Copper forms, with oxygen, likewise peroxide or cupric acid (probably CuO_2 ; 47·68). With chlorine, subchloride (Cu_2Cl ; 98·83); and chloride (CuCl ; 67·15). With sulphur, subsulphuret Cu_2S ; 79·36); and sulphuret (CuS ; 47·68). With phosphorus, tri-phosphuret (Cu_3P ; 126·36); and sub-sesquiphosphuret (Cu_3P_2 ; 157·68).

492. Various compounds of copper, with other metals are used in the arts.—*Spelter*, a species of hard solder, consists of equal parts copper and zinc. It is applied to the surfaces, which are to be joined, in grains, along with a mixture of borax and water: and is then heated intensely. *Brass* contains about 16 parts of copper and 9 of zinc. *Pinchbeck*, 5 of copper and 1 of zinc. *Manheim gold*, which very much resembles the precious metal, consists of 3 parts copper 1 of zinc and a little tin. 2 parts copper and 1 of tin ($\text{Cu}_4 + \text{Sn}$) form the best kind of *speculum metal*:—this alloy cannot be cut by steel, but crumbles when struck: it is perfectly white, and takes a fine polish. *Bell-metal*, which is brittle, consists of 3 parts copper and 1 tin. But 4 parts copper and 1 of tin form a compound which, if held between iron plates to keep it from warping, and plunged at a cherry red heat into cold water, is tough and malleable:—Chinese gongs and cymbals are made of this material—with sometimes a small quantity of nickel. 5 parts copper and 1 of tin afford a very hard metal. *Bronze* consists of 9 parts copper and 1 of tin. Gun-metal contains somewhat less tin:—and an inferior kind, is manufactured with lead, instead of all, or a part of the tin.—The surface

of gun-metal is rendered very hard, by the tin having a tendency outwards. It is curious that increasing the softer metal increases the hardness of the compound.

493. *Black oxide of copper* (CuO) is extremely useful, in chemical analyses. It may be obtained, by mixing pure copper scales with pure nitric acid in a porcelain capsule, so as to form a thick paste. When effervescence has ceased, the mass is to be gently heated, until it is dry; and the resulting green basic salt ($\text{NO}_3 + 3\text{CuO} + \text{HO}$) is to be raised to moderate redness, in a Hessian crucible, until no more nitrous acid vapours are perceived. The decomposition may be accelerated, and rendered uniform, by stirring with a clean glass rod. The pure oxide, which remains, must be levigated: and, as it would absorb moisture from the atmosphere, must be kept in a well-stopped bottle.

494. *Sulphate of the protoxide of copper* ($\text{SO}_3 + \text{CuO}$), or blue vitriol, may be obtained by boiling metallic copper with oil of vitriol.

495. *Ammonio-sulphate of copper* [$(\text{SO}_3 + \text{NH}_4\text{O}) + (\text{NH}_3\text{CuO})$]. When excess of ammonia is added to a strong solution of sulphate of copper, crystals of ammonio-sulphate of copper separate, on cooling, if the liquid is merely poured from one vessel to another.

496. The salts of the suboxide of copper are affected by reagents, very differently from those of the protoxide:—but, in looking for copper, they are always changed into the latter. This alteration is produced, by mere exposure to the air: and so rapidly, that, when suboxide, thrown down by ammonia as a white precipitate, is redissolved by excess, the liquid—which is colourless—will become, at once, a blue solution of the protoxide.

497. Solutions of salts of the black oxide give, with potash, a bulky blue precipitate—the hydrated protoxide ($\text{CuO} + \text{HO}$), which, being boiled, becomes black anhydrous oxide. With caustic ammonia, or its carbonate, bluish or green basic salts, which are soluble in excess—the solution being of a beautiful violet colour, and are similar, in constitution, to the ammoniacal sulphate [495]. With chromate of potash, a reddish brown precipitate, soluble in dilute nitric acid, and also in ammonia—the solution being green. With sulphuretted hydrogen, and hydrosulphuret of ammonia, a black sulphuret—slightly soluble in hydrosulphuret of ammonia, completely so in cyanide of potassium, and decomposed by boiling nitric acid. With cyanide of potassium, a yellowish green precipitate, soluble in excess of the precipitant. With ferrocyanide of potassium, a chocolate brown precipitate, insoluble in dilute acids, but decomposed by caustic potash: and with ferridecyanide of potassium, a yellowish green

precipitate. Iron throws down copper, in the metallic state, from its solutions; and zinc, in the same circumstances, becomes coated with it. The smallest quantity of copper, fused with borax, gives, in the oxidizing flame [101], a green glass, containing the protoxide; but in the reducing flame, a ruby red glass, containing the suboxide. Flame is tinged green, by copper.

498. DIDIMIUM:—*ymb.* D. It is found, with peroxide of cerium, as peroxide—a brown powder. The salts of this metal are of a rose, or amethyst colour. Its equivalent is not yet known.

499. ERBIUM:—*ymb.* Er. It has not been obtained in the metallic state. Its oxide was discovered by Mosander. If, on precipitating a solution of yttria with an alkali, the latter is added gradually, and the precipitates are collected separately, and ignited, the first becomes orange—and is considered to be the oxide of erbium. But little is, however, as yet known about it.

500. GLUCINUM:—*ymb.* G; *equiv.* 26·54. It was discovered by Wöhler, in 1828: and is a rare metal. It is found in the emerald, the beryl, and euclase or prismatic emerald. It may be obtained, by fusing beryl with carbonate of potash; then taking away the silex by solution in dilute hydrochloric acid, and evaporating the result to dryness, after re-solution in water; precipitating the alumina, and glucina, with ammonia: dissolving the former, with a strong solution of carbonate of ammonia, and boiling the filtered solution:—carbonate of glucina separates. The carbonic acid being driven off by heat, glucinum is obtained from the glucina which remains, in the same way as aluminum is obtained, from alumina [430].

501. Glucinum is a grayish black powder. It is not oxidized by the air, at ordinary temperatures; nor, whether hot or cold, by water. But, when heated to redness on platinum foil, it burns brilliantly, and forms glucina. It burns similarly, in oxygen, and chlorine: and in the vapours of iodine, and bromine.

It forms, with oxygen, an oxide (G_2O_3 ; 77·08), called glucina.

502. Potash throws down, from solutions of glucinum, the earth glucina, which is redissolved by excess: but—unlike alumina, also precipitated and redissolved by potash—it is reprecipitated completely, by boiling in a dilute alkaline liquor, or in a solution of sal-ammoniac. Glucina is precipitated, but not redissolved by ammonia. It is precipitated by the carbonates of potash and soda, and redissolved by great excess. Unlike alumina [434], the precipitate it gives, with carbonate of ammonia, is redissolved by excess. It is precipitated, also, not by phosphate of soda.

503. GOLD:—*ymb.* Au; † *equiv.* 98·33. This metal has been known, from the earliest antiquity. It is found, only in the metallic state—either pure, or alloyed: and is often picked up

* *Glukūs*, sweet. *Gr.* From its salts which have a sweetish taste.

† *Aurum*, gold. *Lat.*

in the sand of rivers, being washed down from the mountains. It has been met with, in the county of Wicklow, both in very small grains, and in large masses:—one piece, obtained there, weighed eighteen, and another twenty-two ounces. At present, it is so abundant in California, that the desire of finding it, has become a species of infatuation, which carries away vast multitudes, from their homes and occupations, to that remote country. Gold is usually separated from the sand, &c., with which it is found mixed, by washing.—The metal, on account of its weight, falls rapidly to the bottom of the vessel; and the lighter substances are decanted off. The process of washing is repeated, as often as it is considered necessary: after which, the particles of gold are picked out:—those which cannot be detected by the eye, being agitated with mercury, are dissolved by that metal, which is afterwards driven off, by heat. Gold is separated from silver, by quartation [236].

504. Pure gold is of a reddish yellow colour:—that which is in ordinary use, owes its peculiar shade, to the nature, and quantity, of the metal with which it happens to be alloyed. Its specific gravity is 19·5. It is extremely malleable, and ductile [12]: and so soft that, when used for coin, &c., it requires to be alloyed with copper, &c., to prevent its wearing out with great rapidity. Gold retains its brilliancy in air, and water, for any length of time. It fuses at 2016° ; and, when melted emits a bluish green light—the same as that obtained by transmitting white light through gold leaf. It is soluble in aqua regia [358], and in a mixture of nitric and hydrofluoric acids.

505. The purity of gold, is expressed in “carats.”—A carat is the one-twenty-fourth of the mass—whatever it may be. If twenty-two twenty-fourths are pure gold, it is said to be “twenty-two carats fine:”—this is the fineness of British gold coin. If eighteen twenty-fourths, it is “eighteen carats fine:”—which is the fineness of watch cases, &c., and is the least pure that is stamped at Goldsmith’s Hall.

506. Gold forms, with oxygen, protoxide (AuO ; 106·33); binoxide (AuO_2 ; 114·33); and peroxide (AuO_3 ; 122·33), called from its greater tendency to unite with acids, than oxides, “auric acid.” With chlorine protochloride (AuCl ; 133·80); and terchloride (AuCl_3 ; 204·74). With iodine, protiodide (AuI ; 225·18); and teriodide (AuI_3 ; 478·88). With sulphur, proto-sulphuret (AuS ; 114·33); tersulphuret (AuS_3 ; 146·33), &c.

507. *Peroxide of gold* (AuO_3) being employed in electrotype processes [gal. 93], has become of considerable importance. It may be obtained, by dissolving one part gold, in four of aqua regia: then evaporating the solution to dryness, and redissolving it in water:—some protochloride, and metallic gold will be left. The solution is to be rendered strongly alkaline, with caustic potash: and, when it becomes turbid, is to be gradually mixed—

but not in excess—with a solution of chloride of barium, which precipitates aurate of barytes. After the latter is well washed with water, it is to be decomposed, by being boiled with nitric acid:—nitrate of barytes is formed, and auric acid is precipitated. The latter being decomposed, by the temperature of boiling water, it is dried in vacuo, with sulphuric acid. The gold which is always to be found in the water with which the precipitates are washed, may be recovered. Salts of gold, with oxygen acids, are, as yet, but little known.

508. *Perchloride of gold* (AuCl_3) may be obtained, by dissolving gold in nitro-muriatic acid [358]. If it is required, in the solid form, the solution must be evaporated very cautiously.

509. Solutions of the terchloride of gold, give, with caustic potash, after some time, small quantities of a reddish brown precipitate, which is a combination of auric acid, with terchloride of gold and potash.—No precipitate is thrown down, by potash, from a cold acid solution of gold. Ammonia gives, in tolerably concentrated solutions, a reddish yellow precipitate—the aurate of ammonia, or “fulminating gold.” Protochloride of tin—on adding a drop of nitric acid—gives, in very dilute solutions, a reddish tint; and, in concentrated, a purple red precipitate—the “purple of Cassius,” sometimes verging to a violet, or to a brown red. Sulphuretted hydrogen, or hydrosulphuret of ammonia, gives in neutral, or acid solutions, a brown tersulphuret, partly soluble in potash, completely so in aqua regia, and in hydrosulphuret of ammonia. Protonitrate of mercury, gives a black precipitate. Oxalic acid ($\text{C}_2\text{O}_3 + \text{HO}$) throws down metallic gold in yellow scales, hydrochloric and carbonic acid being produced. $\text{AuCl}_3 + 3(\text{C}_2\text{O}_3 + \text{HO}) = 3\text{HCl} + 6\text{CO}_2 + \text{Au}$. Protosalts of iron, reduce auric acid, when added to its solution—metallic gold being precipitated as a fine brown powder, which acquires a metallic lustre, on being pressed, or rubbed. It is reduced likewise by sulphurous acid [296].

510. *ILMENIUM*:—*ymb. Il.* It is supposed to be associated, as a metallic acid, with niobium and pelopium, in certain tungstates. But its existence is denied by Rose—who asserts it to be niobic contaminated with tungstic acid.

511. *IRIDIUM*:*—*ymb. Ir.*; *equiv.* 98·84. It was discovered by Descotils, and Smithson Tennant in 1803: and is found, only along with osmium, and platinum. When the latter has been removed, by aqua regia, the iridium is separated from the osmium, by fusion with caustic potash: the residual powder is digested in hydrochloric acid, and the same processes are repeated, until no residue is left. The alkaline solution con-

* *Iris*, the rainbow, *Lat.*:—from the variety of colours, exhibited by some of its solutions.

tains oxide of osmium, with a small quantity of iridium—which, after being kept for some weeks, separates spontaneously, in dark coloured thin flakes. There is more iridium than osmium, in the acid solution:—when the latter is slowly evaporated imperfect crystals are produced, which, being dried on blotting paper, and dissolved in water, recrystallize in the octohedral form; and, being then exposed to heat, give pure iridium—oxygen and hydrochloric acid being driven off.

512. Iridium is white, and like platinum, but brittle. Its specific gravity, when fused, is 18·68. It is the most refractory of the metals; but melts, however, before the oxy-hydrogen blow-pipe. It dissolves slowly in aqua regia, the solution being a red brown.

513. It forms, with oxygen, protoxide (IrO ; 106·84); sesquioxide (Ir_2O_3 ; 221·68); deutoxide (IrO_2 ; 114·84); and peroxide (IrO_3 ; 122·84). With chlorine, protochloride (IrCl ; 134·31); sesquichloride (Ir_2Cl_3 ; 304·09); bichloride (IrCl_2 ; 169·78); and perchloride (IrCl_4 ; 205·25). The sulphurets correspond, probably with the oxides, and chlorides. Iridium has a strong affinity for carbon: and combines with it, if held in the flame of a spirit lamp.

514. Iridium gives, with sulphuretted hydrogen, a brown precipitate, soluble in hydrosulphuret of ammonia. Its solutions are discoloured by cyanide, and iodide of potassium; by oxalic acid, and protosulphate of iron.

515. IRON:—*ymb.* Fe ; * *equiv.* 28·0. It has been known from the earliest times; though it rarely occurs in a native state:—meteoric iron contains nickel, and cobalt. It is a most useful, and, fortunately for mankind, a most abundant metal. It is found, sometimes, as a carbonate; at others, combined with oxygen, sulphur, or arsenic: and at others, with siliceous, alumina, &c.—as in clay iron stone. The latter, which is the most common of its ores, is decomposed, by mixing it with limestone and fuel, and applying an intense heat. The silicic acid of the ore, drives off the carbonic acid of the limestone—a substance, between porcelain and glass, and consisting of silicates of lime and alumina, which float on the metal, being produced. If carbon alone were used, the carbonic acid would be driven off; but the iron would form, with the silica and alumina, a glass upon which the fuel would have no effect.

516. Pure, or malleable iron, is obtained from cast iron (which is, probably, about Fe_3C) by “puddling”—that is, burning off its carbon, in a reverberatory furnace. The metal becomes less and less fusible; and there is ultimately obtained a granular mass, which is further united by heat: and is pressed

* *Ferrum*, iron. *Lat.*

together, with great force, by enormous hammers worked by steam. The impure iron is, thus, squeezed out, and the pure is welded together. The metal—which is kept at a proper temperature, by the great pressure employed—is shaped into bars, by a series of rollers.

Sometimes the carbon is driven off, as carbonic acid, by mixing the crude iron with oxide of iron. $\text{Fe}_3\text{O}_4 + \text{Fe}_8\text{C}_2 = \text{Fe}_{11} + 2\text{CO}_2$.

If cast iron is left under water for a considerable time, the metal will become magnetic oxide, and be dissolved out: and the carbon will preserve all the original details.

517. Pure iron is brilliant, and of a bluish white colour. Its specific gravity is 7.788. It is soft, flexible, ductile, and malleable. It requires an enormous temperature to melt it. But it is “welded” at a white heat: the surfaces being united, by an incipient fusion—which is prevented, however, by the presence of a small quantity of copper, lead, &c., in the fire by which it is heated. It is not oxidated, in dry air; but it is peroxidated, when burned in oxygen—some of the oxygen being, however, driven off, by the high temperature. It dissolves, rapidly, in sulphuric, nitric, &c., acids.

518. Iron in the form of a long wire, is not acted on by nitric acid having a specific gravity of 1.35, if one of its ends has been ignited and, when cold, plunged, before any other part of it, into the acid. Also, if platinum and iron wires are fastened together, and the platinum is plunged first into the acid, the iron will be rendered passive. The same effect will be produced, if the platinum is first plunged in, and the iron is then put in contact with it, the platinum being afterwards removed; also, if the iron wire is made the positive pole of a battery [gal. 109]; or if it is put in contact with a wire already passive, and the latter is then withdrawn.—The passive iron does not unite with oxygen, even at the pole of a battery: it does not rust, nor precipitate metallic copper [489] from its solution. Iron is not the only metal, which may be rendered passive.

519. It is not certain that iron decomposes water, at ordinary temperatures, unless an acid is present. But, even carbonic acid, will enable it to do so:—hence the carbonic acid of the atmosphere causes it to form “rust,” which is a carbonate. Rusting is prevented, by immersing the iron in a solution of caustic potash, lime, or soda: or by covering it, with hydrate of lime. This arises, it is likely, from the carbonic acid being absorbed, by these substances. At a red heat, iron decomposes water rapidly. It is scarcely ever found altogether free from carbon: hence the hydrogen evolved by it [181] not being pure, is not inodorous.

520. Iron forms, with oxygen, protoxide (FeO ; 36): peroxide (Fe_2O_3 ; 80) or “red oxide:” and combinations of these—

as the ferroso-ferric or black magnetic oxide ($\text{Fe}_3\text{O}_4 = \text{FeO} + \text{Fe}_2\text{O}_3$), which is found native, in abundance. It forms, also, ferric acid (FeO_3 ; 52). It forms with chlorine, protochloride (FeCl ; 63·47); and perchloride (Fe_2Cl_3 ; 162·41). With iodine, protiodide, (FeI ; 154·85): and sesquiiodide (Fe_2I_3 ; 436·55). With bromine, protobromide (FeBr ; 107·97): and sesquibromide (Fe_2Br_3 ; 295·91). With sulphur, protosulphuret (FeS ; 44); sesquisulphuret (Fe_2S_3 ; 104); magnetic sulphuret, found native, as magnetic pyrites ($\text{Fe}_3\text{S}_4 = \text{FeS} + \text{Fe}_2\text{S}_3$); bisulphuret (FeS_2 ; 60), the iron pyrites of mineralogists. With fluorine, protofluoride (FeF ; 46·86); and perfluoride (Fe_2F_3 ; 112·58). With carbon, compounds the constitution of which is not, as yet, certainly known, &c.

521. *Oxides of iron.* The protoxide is remarkable for its tendency to absorb oxygen. The peroxide is familiar to mineralogists as a natural product, under the name of "red hematite." It causes the red colour of clays; and is formed, at chalybeate springs, by decomposition of carbonate [195]. It is important, as an antidote for arsenic [443]: and may be prepared, as a hydrate, by dissolving together one part chlorate of potash, fourteen parts crystallized protosulphate of iron, and sixteen parts crystallized carbonate of soda: then washing the precipitate well. Black magnetic oxide, is nearly identical with the ferruginous scales obtained in a smith's forge, and with the common loadstone: and is always produced, when iron is heated to redness, in atmospheric air. It causes the dull green colour of bottle glass.

522. *Protosulphate of iron* ($\text{SO}_3 + \text{FeO}$) may be made, by digesting iron wire, in dilute sulphuric acid [180].

523. *Sulphuret of iron* (FeS) may be conveniently obtained, by raising a nail-rod, &c., to a white heat in a forge or other intense fire: and then bringing it in contact with cane brimstone, over water. The sulphuret of iron fuses, as it is formed, and drops into the water: whence it is to be taken, dried, and placed in a bottle—which must be well stopped, to prevent the iron from absorbing oxygen, to which it has a great tendency. Protosulphuret of iron sometimes takes fire spontaneously in coal mines, when moist, on account of this strong affinity for oxygen.

524. STEEL differs from "pig metal [516]," as commercial cast iron is called, by having a smaller quantity of carbon. Cast iron, contains about six parts, in one hundred, carbon; but steel, sometimes, not more than one, in four hundred. Also, the specific gravity of steel is higher.

Steel may be formed, either by leaving a sufficient quantity of carbon in combination with the iron; or, by afterwards adding it. The latter process is called "cementation."—Iron has been converted into steel, by acting upon it when at a high

temperature, and in an air-tight vessel, with coal gas. There are various kinds of steel—

525. *Blistered steel* is made, by placing alternate layers consisting of iron bars and charcoal, in troughs of firestone: and arranging them in a furnace, constructed for the purpose—the heat being applied, for seven, or eight days. When the bars are taken out, they are found to be covered with blisters, and have become steel. Blistered steel, exposed to a tilt-hammer, which strikes about 700 blows in a minute, is increased in tenacity, and solidity; and is termed *tilted steel*.

526. *Shear steel*, so called, because the person who first made it, was in the habit of stamping it with the figure of a pair of shears, is formed by breaking up bars of blistered steel, then placing the fragments in a reverberatory furnace, and, when at a welding heat, uniting each bundle of pieces into one, by a large hammer.—The process being repeated.

527. *Cast steel*, is obtained, by breaking blistered steel into small portions, and putting them, without any admixture, into crucibles. The latter are covered with lids, and placed—imbedded in coke—in a furnace, where they are kept intensely heated, for four or five hours. The steel having melted, it is then poured into moulds: and is, afterwards finished, by hammering, and rolling.

528. Cast steel is excellent, for cutting instruments; but, unlike the other kinds it cannot—without being altered in constitution, and deteriorated—be joined, by welding, to iron, &c.

529. Steel combines with other metals.—It is greatly improved, by the 500th of its weight, silver. If it contains the 100th part of its weight, platinum, it is not so hard as that, made with silver: but it is more tough. Steel combines with gold, &c.: and it forms excellent compounds, with rhodium, iridium, and osmium:—but, from the scarcity of these metals, they are not often used. Acids act very violently, on the alloys of steel, formed with platinum, &c.; which is probably due to the production of galvanic circles [gal. 16]. Pure iron, with three per cent. iridium, or osmium, affords a steel, not so liable to rust as the common kind.

530. *Damascus steel*. Wootz, or Indian steel, is the crude material of Damascus sword blades. It has a “damasked,” or waved appearance: and has been successfully imitated, in Austria, and Prussia, by welding pieces of iron and steel together. Sword blades made of this material, have been struck against iron, without breaking—or even having their edges injured. Steel bars, containing within them a core of iron, are often used in the formation of taps for making hollow screws [mech. 242], &c. This combination possesses all the tenacity of iron: and, at the same time, the strength, and other advantages

of steel. It is not liable, in hardening, to fracture when plunged, at a high temperature, into cold water. Those, only, who are in the habit of working in metals, can appreciate its utility.

531. *Case hardening*, is a process by which the exterior of iron articles, such as fire-irons, &c., is changed into steel. This is effected, very superficially, by dipping them into a saturated solution of yellow prussiate of potash. But, effectually, by heating them, to redness, for some time, in close iron vessels, along with carbonaceous substances; and then plunging them into water.

532. Steel is *hardened*, by heating it to a cherry red, and dipping it in cold water. If it is not raised to the proper temperature, the object will not be attained:—when but moderately hot, it is softened by water. If the steel, in hardening, is heated too much, it will be burned: and, then it becomes valueless, for most purposes.

533. Steel plunged into water, at an elevated temperature, is made exceedingly hard, but, at the same time, extremely brittle. Hence, in many cases—as when it is to have a fine edge, &c.—it requires to be “taken down,” or “tempered.” For this purpose, a portion of its surface being brightened, it is heated by being placed on red hot iron, &c., until the part, which has been cleaned, assumes a hue indicating the required temper. Sometimes only the extremity of the steel is dipped in the water: and a portion, which is left very hot, serves to take down the rest: after which the whole is plunged into the fluid. When the steel is good, its surface becomes sufficiently clean, of itself, to show the proper tint.

534 During the process of tempering, the part which is cleaned becomes, at first, straw coloured, then pink, &c., and finally blue. These colours indicate successively diminishing degrees of hardness: and are selected, according to the purposes for which the instrument is intended. Sometimes a bath of oil, or of fusible metal [heat 106], &c., is used to give the proper temperature. Or, the article is “blazed off”—that is, covered with grease, and heated, until it begins to blaze: the steel is then immersed in water. When the edge can be made so strong, that it is not liable to break, tempering is unnecessary: and the instrument, being left as hard as possible, will last for a long time without requiring to be repaired. It is worthy of notice, that the same angle does not answer for tools, intended to cut different metals. The cutting edge, for brass is 90° : but for iron, it is 60° .

535. The following are the tints, corresponding with the temper, given to various articles—

Very faint yellow, for lancets.

Pale straw, for razors, and surgical instruments.

Full yellow, for pen-knives.

Brown, for scissors; and for chisels intended to cut iron.

Brown with purple spots, for axes, and plane irons.

Purple, for table knives, and large shears.

Bright blue, for swords, and springs.

Full blue, for fine saws, daggers, &c.

Very dark blue, for hand and pit saws.—This is the lowest temper. Springs, &c., lose their elasticity, but not their hardness, by being polished:—it is restored, however, by heating over a clear fire, or in the flame of alcohol, &c.

536. Pig iron, after being cast in moulds, is rendered malleable, by taking away some of its carbon. This is effected, by heating it, when placed in alternate layers with substances having an affinity for that element. In this way, the advantage of casting from patterns, and, at the same time, the tenacity of wrought iron, are secured. The metal produced, is not, indeed, of a superior kind; but it answers very well for many purposes.

537. The proto-salts of iron have a greenish colour: and by absorbing oxygen from the atmosphere, are changed into salts of ferroso-ferric oxide [520]. Salts of the protoxide give, with potash, or ammonia, a whitish hydrate of the protoxide ($\text{FeO} + \text{HO}$), which soon turns green, and ultimately brown red.—The precipitation, by potash is impeded, and that, by ammonia, altogether prevented if ammoniacal salts are present. Acid solutions of the protoxide are not precipitated at all, by sulphuretted hydrogen: neutral solutions, with weak acids, but imperfectly; alkaline solutions, perfectly—a black sulphuret (FeS) being produced. Hydrosulphuret of ammonia precipitates, from all solutions of the protosalts, a black sulphuret (FeS), which soon becomes brown, and is soluble in nitric, or hydrochloric acid, but insoluble in alkalis, or alkaline sulphurets. Ferrocyanide of potassium throws down, in solutions of the proto-salts, a bluish white ferrocyanide of potassium and iron ($2\text{FeCy}_3 + \text{K} + 3\text{Fe}$)—which, by absorbing oxygen, becomes Prussian blue ($3\text{FeCy}_3 + 2\text{Fe}_2$), all of the potassium, and one atom of iron, for every three atoms of the compound, being oxidized. This change is effected, instantaneously, by nitric acid, or chlorine. Ferridcyanide of potassium gives, with salts of the protoxide, a blue precipitate—the ferridcyanide of iron ($2\text{FeCy}_3 + 3\text{Fe}$). Sulphocyanide of potassium has no effect on solutions of salts of the protoxide, which are quite free from peroxide.

538. The persalts of iron have a more or less reddish colour. Compounds of the peroxide give, with potash, or ammonia, a bulky reddish brown precipitate—the hydrated peroxide ($\text{Fe}_2\text{O}_3 + \text{HO}$), which is insoluble in salts of ammonia. With tannic, or gallic acid, a deep violet, or even black—the tannate or gallate of

iron. Peroxide, in either its acid, or neutral, solutions is decomposed by sulphuretted hydrogen—water and protoxide being formed, and sulphur deposited. $\text{Fe}_2\text{O}_3 + \text{HS} = 2\text{FeO} + \text{HO} + \text{S}$. Hydrosulphuret of ammonia precipitates the black protosulphuret, from neutral solutions of the per-salts—the peroxide being first changed by the re-agent into protoxide. Ferrocyanide of potassium produces the precipitate of Prussian blue *at once*, with solution of the salts of the peroxide. Ferridcyanide of potassium merely deepens the colour of solutions of the peroxide. Sulphocyanide of potassium gives a most beautiful blood red colour to solutions containing the peroxide. It is due to the formation of sulphocyanide of iron ($\text{Fe}_2 + 3\text{C}_2\text{N.S}_2$), a compound which is found in the blood [172]. This test will enable us to detect the most minute quantities of iron.

The tests for salts of the sesquioxide are so decided, that, before looking for iron, it is usually peroxidized, if not so already :—this is effected, by boiling the solution with a little nitric acid.

Borax, or phosphate of soda and ammonia, forms with salts of iron, in the oxidizing flame, dark red buttons—which, in the reducing flame, become bottle green, on account of the peroxide being changed to magnetic oxide. But these colours disappear, to a greater or less extent, on cooling—particularly with the phosphate of soda and ammonia.

539. LANTHANUM :—*symp.* L ; *equiv.* 48. It was discovered, by Mosander, that, if the protoxide of cerium is changed into peroxide, by calcination, a portion of the result still dissolves, in dilute nitric acid. And he found this portion to be, in reality, the oxide of a metal, which he termed “lanthanum.”

540. The protoxide of lanthanum, has a slightly alkaline reaction. It gives white precipitates, with the caustic alkalies, and the alkaline carbonates.

541. LEAD :—*symp.* Pb ; † *equiv.* 103·73. This metal was known to the ancients. It is found, in combination with a variety of substances. But, for the purposes of commerce, it is obtained from “galena,” a native sulphuret, by exposing it, at first, to a moderately high heat, in a reverberatory furnace; then, after about half of it has become sulphate of lead, mixing it well and, the temperature being rapidly raised, fluxing the whole. Metallic lead, and sulphurous acid are the results. $(\text{SO}_3 + \text{PbO}) + \text{PbS} = 2\text{Pb} + 2\text{SO}_2$. The lead, so obtained, generally contains silver, iron, and copper.

542. Lead is of a bluish white colour. It is very brilliant, but soon tarnishes in the air—and is then protected from further action, by the coating formed upon it. Its specific gravity is 11·44. It is very soft, flexible, and inelastic. It is ductile, and extremely malleable—but less tenacious, than other ductile

* *Lanthano*, I lie hid. *Gr.*

† From *plumbum*, lead. *Lat.*

metals. It melts at 612° , a heat below redness, and contracts, in cooling. Water containing atmospheric air, oxidizes it rapidly—scales of carbonate of the protoxide being formed, with the oxygen and carbonic acid of the air. Hence, water that is kept in leaden cisterns, may become poisonous [270]. But the presence of saline matters retards, or prevents, the action of the air, by forming a coating of insoluble compounds of lead. The more insoluble these are, the better their preservative power:—the three thousandth part phosphate of soda, or iodide of potassium, in distilled water, prevents any action whatever. Spring water, on account of the salts contained in it, has very often not the least effect on lead; and may therefore, be safely drank from leaden pipes, or cisterns. Lead is scarcely affected by sulphuric, or hydrochloric acid, except at high temperatures. It is not corroded, by the vegetable acids: although, in some instances—as happens with copper [490]—their presence accelerates the absorption of oxygen from the atmosphere. It is rapidly dissolved, by nitric acid.

543. Lead forms, with oxygen, suboxide (Pb_2O ; 215·46); protoxide (PbO ; 111·73), red oxide (Pb_3O_4 ; 343·19), peroxide (PbO_2 ; 119·73). With chlorine, chloride ($PbCl$; 139·20), called, on account of assuming the appearance of horn, when heated, “plumbum corneum,”* and “horn lead.” With iodine, iodide (PbI ; 230·58). With bromine, bromide ($PbBr$; 183·70). With sulphur, sulphuret (PbS ; 119·73). With fluorine, fluoride (PbF ; 122·59), &c.

544. *Oxides of lead.* The gray film, which is produced on the surface of melted lead, is *protoxide*. When this is exposed to heat and air, until it becomes of a uniform yellow colour, it is called “massicott”—and, if it is partially fused, by heat, “litharge.”

The acidity of weak wines is, sometimes, nefariously corrected by litharge which, with the acetic acid of the wine, forms acetate of lead—called, from its sweet taste, “sugar of lead.” Sulphuretted hydrogen will, at once, indicate the presence of the lead. Burgundy, and other wines, containing tartrate of potash, cannot hold lead in solution—tartrate of lead being insoluble. The effect of acetate of lead may be averted, by a plentiful dose of Epsom salt (sulphate of magnesia), or glauber salt (sulphate of potash): insoluble sulphate of lead being produced by them. The poisonous action of acetate of lead has been found to be neutralized, also, by sugar. The protoxide readily unites with earthy substances, forming with them a colourless glass: and it is the base of all the salts of lead.

Red oxide, the “minimum,” and “red lead” of commerce, consists, probably, of two atoms protoxide, and one peroxide.

* Horny lead. *Lat.*

Digested with nitric acid, it is decomposed into protoxide, and peroxide—the former being dissolved, and the latter being left behind, as in insoluble powder. The brilliancy of red lead is sometimes impaired, by excess of protoxide: which may be removed by boiling in a solution of neutral acetate of lead.

Peroxide, if heated to redness, is changed into protoxide—oxygen being evolved.

545. *Ceruse*, or the “white lead” used as a paint, is one of the most important of the compounds of this metal. It is a combination of basic carbonates, in variable proportions; and is made, by exposing sheets of lead to fumes, arising from vessels containing weak vinegar.—The lead being oxidized by the oxygen of the atmosphere, a basic acetate is first produced. This is changed by the carbonic acid of the atmosphere, into basic carbonate, and neutral acetate. The latter, combining with a new portion of lead, again forms basic acetate; and is again decomposed, as before. And thus, a small quantity of acetate may form an indefinitely large one of ceruse. The process is greatly improved, by exposing a mixture containing well-ground litharge, and one per cent. acetate of lead, to the carbonic acid evolved in a brewery, &c.

546. *Neutral acetate of lead* ($\bar{A} + PbO$), may be obtained, sufficiently pure, by dissolving the best commercial sugar of lead in distilled water.

547. The soluble salts of lead—but more especially the carbonate—and its oxides, often produce the most disastrous consequences, although introduced into the system, by very small doses at a time. This is clearly shown, by the paralyses of the extremities, which they often cause: and by the dreadful disease, called “painter’s cholic.” But these terrible effects would be diminished, or prevented, by the use of minute quantities of sulphuric acid [308].

548. Various compounds of lead, with other metals, are used in the arts.—*Type metal* consists of 3 parts lead, and 1 antimony. *Pewter*, of which almost all foreign tin may be considered as a species, consists of tin and lead; and, the better kinds, of tin, with antimony and bismuth, and but little lead. *Soft solder* is composed of from 2 parts tin, and 1 lead, to 1 part tin, and 3 lead.—A compound, containing equal parts of both, answers well for joining tinned iron, copper, &c. The larger the amount of tin, the more fusible the solder;—the finer kinds melt, at about 360° ; and the coarser, at about 500° . Resin, &c., cause the solder to adhere to the metal, by preventing oxidation, or removing the oxide; a solution of chloride of zinc, or of sal-ammoniac, facilitates the union still more. Tin-foil, wetted with a strong solution of sal-ammoniac, answers well, for fine joints in brass.

549. The soluble salts of lead, in the neutral state, redden litmus paper; and are decomposed, at a red heat.

Lead, in solution, gives, with potash, or ammonia, white precipitates, which are basic salts, easily soluble in ammonia, but with difficulty in potash. Ammonia throws down no precipitate, with acetate of lead, a soluble triacetate being formed. Sulphuretted hydrogen, and hydrosulphuret of ammonia, give, with the compounds of lead, a black sulphuret (PbS), which is decomposed by boiling concentrated nitric acid.—When the solution contains much mineral acid, the sulphuretted hydrogen causes no precipitate, until water is added. The alkaline carbonates, give, a white carbonate ($CO_3 + PbO$) [547]. Sulphuric acid, and the sulphates, a white sulphate ($SO_4 + PbO$), insoluble in water, and in dilute sulphuric acid—particularly in the latter. Hydrochloric acid, and the soluble chlorides, a white chloride ($PbCl$), soluble in a large quantity of water—especially if heat is applied, but very difficult of solution, in nitric, or hydrochloric acid. Chromate of potash, a yellow chromate ($CrO_3 + PbO$), soluble in caustic potash, but not in nitric acid.—This chromate is used very extensively as yellow paint. Ferrocyanide of potassium, a white ferrocyanide.

550. Lead is separated from its salts, in the metallic state, by iron, or zinc.—If a piece of the latter is suspended, by a thread, in a solution containing one part acetate of lead, and twenty-four parts water, the lead will be deposited on the zinc, in an arborescent form—constituting what is called, from its appearance, “arbor Saturni.”*

551. LITHIUM; †—*ymb.* L; *equiv.* 6.55. Sir H. Davy obtained this metal, by means of galvanism, from its oxide. The latter was discovered, in 1818, by Ardfwedson; and was named by him *lithion*, on account of his having detected it in an earthy mineral: but it has since been termed “lithia.” It is procured, from *spodumene*, which is found, among other places, at Killiney, in the county Dublin; and is a double silicate of lithia and alumina.—The mineral is to be carefully pulverized: then, mixed

* “The tree of Saturn.” *Lat.*—The ancients gave the following names, and symbols, to those metals with which they were familiar—

Metals.	Names.	Symbols.
Gold,	The Sun,	☉
Silver,	The Moon,	☾
Mercury,	Mercury,	☿
Copper,	Venus,	♀
Iron,	Mars,	♂
Tin,	Jupiter,	♃
Lead,	Saturn,	♄

† *Lithos*, a stone. *Gr.*

with fluor spar, and digested with oil of vitriol. The silica present, forming with the hydrofluoric acid fluoride of silicon [416] and water, passes off; the lime, alumina, and lithia unite with the sulphuric acid. When the other sulphates are dissolved by a small quantity of water, the insoluble sulphate of lime is left behind; and [434] the alumina is precipitated from the filtered solution, by ammonia. The clear liquor is then evaporated: and, what is left being ignited—to decompose the sulphate of ammonia, the residue, which is sulphate of lithia, having been dissolved, is decomposed by nitrate of barytes:—sulphate of barytes is thrown down, and nitrate of lithia is left in solution. When this is evaporated, and decomposed by heat, the residue is lithia. Metallic lithium is procured from this, by galvanic action.

552. Lithium is white, like sodium. It is immediately oxidized, by the atmosphere—lithia being produced.

553. It forms, with oxygen, an oxide (LO ; 14·55)—“lithia,” which is an alkali; and possesses stronger neutralizing powers, than potash, or soda. With chlorine, chloride (LCl ; 42·02). With fluorine, fluoride (LF ; 25·41), &c.

554. When the salts of lithia are heated on platinum wire, by means of the blow-pipe, like strontia, they tinge the flame, red:—if, however, soda is present, it produces its own yellow colour. When lithia is fused on platinum foil, it leaves a yellow trace, round the spot where it was placed. This arises from oxidation of the platinum—which recovers its metallic appearance, on being washed, and heated. It is distinguished from baryta, strontia, and lime, by forming soluble salts with the sulphuric, and oxalic acids; and from magnesia, by its carbonate, which is sparingly soluble in water, forming a solution, that has an alkaline reaction.

555. MAGNESIUM: *—*ymb.* Mg ; *equiv.* 12·62. It was obtained, in small quantities, by Davy, in 1807; but, it is procured, with great facility by the following process—employed by Bussey, in 1829. Small pieces of anhydrous chloride of magnesium are placed upon bits of potassium, in a hard glass tube, hermetically sealed at one end. After the chloride has been heated, almost to its point of fusion, a lamp is applied to the potassium:—the latter, rising in vapour, will pass through the chloride, and vivid incandescence will be produced. When the action has terminated, and the whole is quite cool, the resulting chloride of potassium is washed away from the magnesium, with water. $MgCl + K = KCl + Mg$.

556. Magnesium is white, like silver. It is malleable. It

* From the earth magnesia, the name of which, according to Fourcroy, is derived from the word “magnet” on account of some properties it was supposed to possess.

melts, at a red heat. It is not oxidized in dry air, nor in boiling water: but it slowly combines with oxygen, in damp air. Heated to redness in atmospheric air, or oxygen, it burns brilliantly, forming magnesia. It takes fire, spontaneously, in chlorine; and dissolves, with facility, in dilute acids.

557. Magnesium forms, with oxygen, an oxide (MgO ; 20.62)—“magnesia,” an alkaline earth, which is found abundantly, as a carbonate, united with carbonate of lime, in magnesian limestone $[(CO_2 + CaO) + (CO_2 + MgO)]$. Unlike lime, it does not emit heat, when combining with water. Magnesium forms, with chlorine, chloride ($MgCl$; 48.09). With iodine, iodide (MgI ; 139.47). With bromine, bromide ($MgBr$; 92.59). With fluorine, fluoride (MgF ; 31.48), &c.

558. Magnesian salts, in solution, are recognised, by forming, with ammonia, a bulky white hydrate ($MgO + HO$). The latter is not produced, in acid solutions: nor if ammoniacal salts are present—since magnesia forms, with ammonia, soluble double salts. Caustic potash causes a similar precipitate—which disappears, on adding sal-ammoniac, but is re-produced by boiling with excess of potash. Carbonate of potash throws down, in neutral solutions, when ammoniacal salts are not present, a bulky white precipitate $[3(CO_2 + MgO + HO) + (MgO + HO)]$, some of which is held dissolved, as bicarbonate, until the carbonic acid, which rendered it soluble, is expelled, by boiling. Phosphate of soda—if ammonia is added—precipitates a crystalline basic phosphate of magnesia and ammonia $[PO_5 + (2MgO + NH_4O) + 12Aq]$ which is insoluble in ammoniacal salts, but dissolves in free acids. If the solution contains but a small quantity of the magnesian salt, the crystalline precipitate forms only on the sides of the vessel—and but slowly there, unless it is rubbed with a glass rod. Before adding the phosphate of soda, it is proper to precipitate barytes, strontia, lime, and the other alkaline earths, by heating with sulphate of potash, and oxalate of ammonia. The sulphate of magnesia, unlike that of lime, &c., is very soluble: and oxalate of ammonia forms no precipitate with magnesian salts, when those of ammonia are present.

If magnesia, or one of its compounds is moistened with a solution of protonitrate of cobalt, and then strongly heated on charcoal, by the blow-pipe, a slight flesh tint is produced; and it becomes somewhat stronger, on cooling.

559. MANGANESE: *—*ymb.* *Mn*; *equiv.* 27.56. In the form of black oxide, it was discovered by Gahn, in 1774: and was shown to contain a peculiar metal, by Scheele, soon after. It was first called “magnesium:” but afterwards “manganesium,” from manganese, the name by which its peroxide was long

* From “magnesia,” its black oxide having been called “black magnesia.”

known. It is very generally, but not very abundantly, diffused through the animal, vegetable, and mineral kingdoms: and may be obtained, in the metallic state, by heating to full redness, in a platinum crucible a mixture of chloride of manganese, carbonate of soda, and sal-ammoniac. Chloride of sodium, and carbonate of manganese, are first formed. $MnCl + (CO_2 + NaO) = NaCl + (CO_2 + MnO)$. The carbonate is then decomposed, the carbonic acid being driven off; and the oxide of manganese is prevented from combining with any more oxygen, by the sal-ammoniac—which gives hydrogen with facility. The resulting oxide, having been mixed with an equal weight of lampblack, and made into a dough with oil, is to be placed in a crucible coated with clay and charcoal powder; and, when it has been subjected for two hours, to the highest heat of a smith's forge, a button of metallic manganese will be obtained.

560. It is a grayish white, granular metal. Its specific gravity is 8.013. It is brittle and very refractory—requiring the most intense heat of a smith's forge for fusion. It soon oxidizes, in the air, becoming a black powder. It decomposes water slowly, at ordinary temperatures: but quickly, at a red heat. It dissolves rapidly, in dilute sulphuric acid.

561. Manganese forms, with oxygen, protoxide (MnO ; 35.56); sesquioxide (Mn_2O_3 ; 79.12); peroxide (MnO_2 ; 43.56)—the black oxide [156], called, also, “glass maker's soap,” from its whitening glass [392]. It is very important in the arts, &c. When found native, it is almost always contaminated with other substances—generally, with oxide of iron. Manganese forms, also, red oxide (Mn_3O_4 ; 114.68, believed, by some, to consist of one atom of peroxide, and two of protoxide); *varvicite* (Mn_4O_7 ; 166.24, supposed to consist of two atoms of peroxide, and one of sesquioxide), so called, because found as a natural production, thus named, in Warwickshire; manganic acid (MnO_3 ; 51.56), which cannot be obtained, except, in combination—since it resolves itself, spontaneously, into peroxide and oxygen: and permanganic acid (Mn_2O_7 ; 111.12). With chlorine, protochloride ($MnCl$; 63.03); perchloride (Mn_2Cl_7 ; 303.41). With sulphur, sulphuret (MnS ; 43.56). With fluorine, perfluoride (Mn_2F_7 ; 187.14), &c.

562. The proto-salts of manganese are colourless, or of a pale red colour. The per-salts produce red, or green solutions—which are changed, by sulphurous acid, or sulphuretted hydrogen, to solutions of salts of the protoxide. Both the protoxide and its hydrate, become brown, by exposure to the air—being altered to peroxide.

563. The protosalts, in solution, give, with potash, or ammonia, a whitish hydrated protoxide ($MnO + HO$), which,

by absorbing oxygen from the air, becomes brownish, and finally, deep blackish brown—being changed into hydrated peroxide. The precipitate thrown down by potash, is diminished, and that, by ammonia, is prevented, by sal-ammoniac—which dissolves the protoxide, forming double salts of manganese and ammonia, that, by exposure to the air, become turbid, and deposit a dark brown hydrated sesquioxide ($Mn_2O_3 + HO$). They give with the alkaline carbonates, a white carbonate: and with phosphate of soda, a white phosphate. Acid solutions give, with sulphuretted hydrogen, and those that are alkaline, with hydrosulphuret of ammonia, a bright flesh-red sulphuret (MnS), which is soluble in hydrochloric, or nitric acid, and turns brown, by exposure to the air. The proto-salts give, with ferrocyanide of potassium, a ferrocyanide, which, being at first white, becomes pale red, and is soluble in free acids: and, with ferridcyanide of potassium, a brown ferridcyanide.

564. Compounds of manganese, fused with carbonate of soda, in the *outer* flame of the blow-pipe, become green, while hot; but blue-green, and turbid, when cool—manganate of soda ($MnO_3 + NaO$) being produced. The effect is rendered more perceptible, by the addition of a small quantity of nitre. Compounds of manganese, fused with borax, in the *outer* flame of the blow-pipe, form a violet red, or—if there is much manganese—a black button; but the colour is destroyed, by the *inner* flame. The same effects are produced, if phosphate of soda and ammonia is employed, instead of borax: except that a black button is never obtained, and the inner flame decolourizes with greater rapidity.

565. MERCURY:—*symb.* Hg ; * *equiv.* 100·07. It was known to the ancients: and received its name from the Persians, who supposed its properties next to those of gold—and, therefore, called it after the planet nearest to the sun [550, note]. It is found in the metallic state—sometimes in combination with gold, and silver: but it is most usually obtained, from “cinnabar,” a native sulphuret, by heating with lime, or iron filings. Sulphuret of calcium—or of iron—and oxide of mercury, are the results: and the latter is then decomposed, by the heat, into metallic mercury, which passes off in vapour and is condensed, and oxygen, which escapes.

In another process, the cinnabar is roasted in kilns, to burn off the sulphur:—sulphurous acid is evolved, and metallic mercury distils over, and is condensed.

566. The mercury of commerce is adulterated with tin, lead, and bismuth; but it is purified, by distillation, or by being kept in contact with dilute nitric acid—which seizes on

* From *Hydrargyrum* (liquid silver), its Latin name—*hudôr*, water, and *arguros*, silver. *Gr.*

the impurities, and does not act on the mercury, until they are dissolved. But the process is stopped, before that takes place.

567. Mercury is white, and very brilliant. At 60° , its specific gravity is 13.568. Unlike any other metal, it is liquid at ordinary temperatures. It solidifies, at 39° below zero—contracting very much, at the moment of congelation; and its specific gravity is then 14.0. It boils at 662° . When pure, it is not tarnished by air, or moisture:—but, in the form of vapour, it is slowly oxidized by the atmosphere, or by oxygen—becoming peroxide. It is oxidized, by boiling sulphuric acid, sulphurous acid [306] being evolved. Nitric acid acts powerfully upon it, nitric oxide being given off in large quantities.

568. Mercury forms with oxygen, suboxide (Hg_2O ; 208.14), called “black oxide;” and peroxide (HgO ; 108.07), called, “red precipitate.” With chlorine, subchloride (Hg_2Cl ; 235.61), called also, “calomel,” and “horn silver;” and perchloride, ($HgCl$; 135.54), called “corrosive sublimate.” With iodine, subiodide (Hg_2I ; 326.99); protiodide (HgI ; 226.92); and sesquiiodide (Hg_4I_3 ; 780.79). With bromine, subbromide (Hg_2Br ; 280.11); and perbromide ($HgBr$; 180.04). With sulphur, sub-sulphuret (Hg_2S ; 216.14); and persulphuret (HgS ; 116.07), known as “factitious cinnabar,” and, when reduced to powder, as “vermilion.”

569. *The peroxide of mercury* is nearly black when hot, but red, when cold [heat 3]. If obtained, by precipitating corrosive sublimate with caustic potash, it is yellow; and, though identical in constitution, with the red, it has such a difference of properties, as indicates it to be in quite another allotropic state [154]. The yellow is dissolved, at once, by oxalic acid; and is changed, by heat, into the red.

570. *Protonitrate of mercury* ($NO_6 + Hg_2O$) may be formed, by gently heating nine parts nitric acid, specific gravity 1.23, with ten parts mercury: and, when gas is no longer disengaged, boiling the solution along with the undissolved mercury—the water being replaced, according as it is evaporated—until, if common salt is added in excess, protochloride of zinc will produce no further precipitate. The whole is then to be agitated, until it is cold: and the resulting crystals are to be dissolved in twenty parts cold water, slightly acidulated with nitric acid. The solution is to be filtered, and kept in a bottle, the bottom of which is covered with mercury.

571. *Perchloride of mercury* ($HgCl$), may be obtained sufficiently pure, by recrystallizing that of commerce.

572. Mercury unites with many metals, forming compounds, which, if soft at ordinary temperatures, are termed “amalgams.”—It unites, very easily, with gold, silver, lead, tin,

bismuth, and zinc; not easily, with copper, arsenic, and antimony; and scarcely at all, with platinum, or iron. Looking-glasses are "silvered" with an amalgam consisting of tin and mercury. Some of the metals with which mercury unites, rise along with it, to a greater or less extent, in distillation [heat 88].

573. The soluble salts of the suboxide of mercury redden litmus paper. Potash gives, with their solutions, the black suboxide. Ammonia gives a black precipitate, which is a basic double salt of mercury and ammonia (for example, with the nitrate, it is $\text{NO}_3 + \text{NH}_3 + 2\text{Hg}_2\text{O}$). Phosphate of soda, gives a white precipitate; iodide of potassium, a greenish yellow, soluble in excess; chromate of potash, a red; sulphuretted hydrogen, and hydrosulphuret of ammonia, black subsulphurets—dissolved, and decomposed, by aqua regia, but not by boiling nitric acid. Hydrochloric acid, and the soluble metallic chlorides, give a dazzling white sub-chloride, that dissolves in aqua regia, or chlorine water—becoming perchloride: and is decomposed, by ammonia, and potash—black suboxide being separated. Protochloride of tin gives a gray precipitate, which consists of metallic mercury, and changes into globules, by heating and agitation, but, more readily, by boiling with hydrochloric acid. Ferrocyanide of potassium, gives a white precipitate, which gradually becomes bluish.

574. The persalts give, with potash, a yellow hydrated oxide ($\text{HgO} + \text{HO}$):—this precipitate is reddish brown, with an insufficient quantity of the re-agent. Ammonia gives a white precipitate, which is a compound of amidide of mercury (HgNH_2), and some of the undecomposed salt. Thus, with protochloride, the reaction is $2\text{HgCl} + 2\text{NH}_3 = (\text{HgNH}_2 + \text{HgCl}) + (\text{HCl} + \text{NH}_3)$. This salt is produced, also, when the reddish brown precipitate, thrown down from the solution of a salt of the oxide of mercury, by the fixed alkaline carbonates, is acted on by ammoniacal salts. Sulphuretted hydrogen, and hydrosulphuret of ammonia, in small quantity, the solution being agitated, give a white precipitate, consisting of sulphuret of mercury and undecomposed salt: but, in larger quantities, a yellow, orange, brown, red, or black—the resulting sulphuret being soluble in aqua regia, but not in boiling nitric acid. Phosphate of soda gives a white precipitate. Iodide of potassium gives a red precipitate, which is soluble in excess, and crystallizes, from a hot solution, in beautiful crimson spangles. Protochloride of tin produces the same effect, as with solution of the suboxide [573]. Ferrocyanide of potassium gives a white precipitate, which gradually becomes bluish. Ferridcyanide of potassium gives, with solutions of the nitrate and sulphate, but not with that of the chloride, a yellow precipitate.

575. Mercury may be detected, in solution, by placing a drop of the suspected liquor on clean gold, and touching the moistened surface, with iron wire, or the blade of a penknife:—the point of contact will become white, on account of an amalgam of gold being formed. The solution of any mercurial salt, rubbed on clean copper, gives a brilliant surface of metallic mercury. The oxides of mercury are reduced, in close vessels, by mere heat.

576. Many animal, and vegetable substances, slowly convert perchloride of mercury, into subchloride:—albumen produces this effect rapidly, and forms a harmless compound with the resulting calomel. Hence white of eggs is an antidote for corrosive sublimate.

CHAPTER V.

The Metals continued—Molybdenum, 577.—Nickel, 582.—Niobium, 588.—Osmium, 590.—Palladium, 594.—Pelopium, 598.—Platinum, 599.—Potassium, 607.—Rhodium, 625.—Ruthenium, 631.—Silver, 635.—Sodium, 643.—Strontium, 653.—Tellurium, 656.—Terbium, 659.—Thorium, 660.—Tin, 663.—Titanium, 670.—Tungsten, 674.—Uranium, 679.—Vanadium, 683.—Yttrium, 688.—Zinc, 692.—Zirconium, 697.—Comportment of the Metals, with re-agents, 700.

577. THE METALS CONTINUED—MOLYBDENUM.*—*ymb. Mo*; *equiv.* 47·96. It was discovered by Hielm, in 1782; and is obtained, from its bisulphuret—which very much resembles “black lead,” in appearance—by digesting it, in a state of minute division, with aqua regia, and heating the residue, to expel the sulphuric acid. Molybdic acid, a heavy white powder, is left behind: and when this is heated, as strongly as possible, with charcoal, in a smith’s forge, metallic molybdenum is the result.

578. Molybdenum is a brittle, white metal. Its specific gravity is 8·6. It has never been more than semifused. Heated in the atmosphere, it becomes molybdic acid. It is acted upon only by concentrated nitric, and sulphuric, acids; and by aqua regia.

579. Molybdenum forms, with oxygen, molybdous oxide (MoO ; 55·96); molybdic oxide (MoO_2 ; 63·96); molybdic acid (MoO_3 ; 71·96); and molybdate of molybdenum ($\text{Mo}_3\text{O}_8 = \text{MoO}_3 + 2\text{MoO}_3$; 207·88), a blue powder sometimes used in calico printing. With sulphur, bisulphuret (MoS_2 ; 79·96): tersulphuret (MoS_3 ; 95·96); and persulphuret (MoS_4 ; 111·96), &c.

580. Molybdous oxide, in solution, gives with potash, and ammonia, a brownish black precipitate: and with the carbonates of potash, and ammonia, a similar precipitate, slightly soluble in the former—but more so, in the latter. With hydrosulphuret of ammonia, a yellowish brown precipitate, soluble in excess.

Molybdic oxide is completely thrown down by sal-ammoniac, as a reddish brown hydrate, which is similar in appearance, to hydrated sesquioxide of iron, and which is dissolved by carbonate of ammonia, but reprecipitated by boiling.

The oxides of molybdenum give to microcosmic salt a green, and to borax a brownish red colour, in the inner flame of blow-pipe.

* *Molubdos*, lead, *Gr.*; because found in a mineral, long supposed to be “black lead.”

581. Molybdic acid, in an acid solution, gives with sulphuretted hydrogen, in excess—after a while—a brown precipitate, which subsides slowly, leaving the supernatant liquor blue, or green. Nitrate of silver gives, with solutions of molybdic acid, a white precipitate, which is soluble in a large quantity of water, in ammonia, and in nitric acid. Chloride of barium gives a white precipitate, soluble in nitric acid. Metallic zinc or tin, when free hydrochloric acid is present, colours solutions containing this acid, blue, then green, and finally black.

582. NICKEL: *—*symb.* Ni; *equiv.* 29·53. It was discovered by Cronstedt, in 1751: and is best obtained from *speiss*, an artificial arseniuret produced in the manufacture of “smalt” [483], by reducing it to a fine powder, and then digesting it with sulphuric acid, which contains a fourth part nitric acid, and is diluted with water. This forms sulphate of nickel, and arsenious acid:—the latter is separated by concentrating, then leaving the solution at rest, for some hours, and afterwards filtering. A solution of carbonate of potash is next added to the clear liquor, until the green precipitate thrown down ceases to be re-dissolved;—after which, if left quiet, the double sulphate of potash and nickel will crystallize, of itself. The crystals being dissolved, any copper contained in them, is separated by sulphuretted hydrogen—as also any arsenic, in the form of sesquisulphuret. The free sulphuric acid is then driven off, by heat: the oxides of nickel, cobalt, and iron are precipitated, by ammonia: and the two former being dissolved, by excess, are removed. The cobalt having been separated from the nickel, by the method I have already described [478], oxide of nickel, or oxalate is again formed. Metallic nickel is obtained, from the oxide, by acting upon it when at a high temperature, with carbon, or hydrogen; and, from the oxalate by heating it in close vessels. $C_2O_3 + NiO = 2CO_2 + Ni$. The nickel is in the form of a light sponge.

583. Nickel is white, like silver. Its specific gravity is, after fusion, 8·5:—but it is rendered more dense, by hammering. It is malleable, both when hot, and cold. It is rather more fusible than iron, but less magnetic. Its magnetism, which is permanent like that of steel, is altogether destroyed by the presence of very little arsenic, or by a temperature of 630°. It is almost as little liable to tarnish, in damp air, as platinum, gold, or silver: but it is partially, though not rapidly, oxidized at a red heat. It is acted upon, with difficulty, by hydrochloric, or sulphuric acid: but is dissolved, with facility, by nitric acid.

584. Nickel forms with oxygen, protoxide (NiO ; 37·53); and peroxide (Ni_2O_3 ; 83·06). With chlorine, chloride ($NiCl$; 65).

* So called, because found in ores, termed by the German miners, “kupfer nickel,” *false copper*; being mistaken by them for that metal.

With sulphur, disulphuret (Ni_2S ; 75.06); protosulphuret (NiS ; 45.53). With phosphorus, subphosphuret (Ni_2P_2 ; 151.23), &c.

585. Nickel is used in the arts, to produce, with other metals, some very beautiful compounds.—1 part nickel, and 5 of brass, form the Chinese “packfong;” and also an inferior kind of German silver. Increasing the nickel up to 6 parts, gives combinations of progressively increasing beauty, but of greater cost, also.—A combination, containing 6 parts nickel, can scarcely be distinguished from silver. When there is much nickel, arsenic, even in minute quantities—and it is very difficult to banish it altogether—would render the metal hard, and liable to flaws.

586. The protoxide is the only oxide, that forms salts;—it is precipitated, by potash, as a light green hydrate ($\text{NiO} + \text{HO}$) which is dissolved by carbonate of ammonia, the solution being green. The same precipitate is thrown down, by ammonia, and is redissolved by excess, the solution being blue:—ammonia gives no precipitate, in the presence of ammoniacal salts, or of free acid. The alkaline carbonates throw down a green precipitate—which is redissolved by the carbonate of ammonia. Sulphuretted hydrogen throws down, from alkaline, and hydrosulphuret of ammonia from neutral solutions, a black sulphuret (NiS) readily soluble in aqua regia:—the fluid from which this precipitate separates, is generally brownish, a small quantity being redissolved, on account of the presence of free ammonia, or pentasulphuret of ammonia. Cyanide of potassium, throws down a greenish yellow cyanide (NiCy), which dissolves in excess. a double cyanide of nickel and potassium ($\text{NiCy} + \text{KCy}$) being produced:—sulphuric, or hydrochloric acid, reprecipitates the cyanide of nickel. Ferrocyanide of potassium, throws down a yellowish green: and ferridecyanide of potassium, a yellowish brown precipitate.

587. Borax and microcosmic salt give, with compounds of nickel, in the outer flame of the blow-pipe, dark yellow buttons, which have a tinge of red brown, but become almost colourless, by cooling:—the addition of nitre, or carbonate of potash, changes the colour to blue, or dark purple. The button formed by microcosmic salt is not altered by the inner flame, but that obtained with borax, is rendered by it gray, and turbid.

588. NIOBIUM:—*symb.* Nb. The existence of this metal was pointed out, by Rose. It is obtained from the American, or Bavarian tantalite, as niobic acid.

589. Ferrocyanide, and sulphocyanide, of potassium give, with solutions containing niobium, a dark yellow precipitate.

* This metal and *pelopium*, obtained their names, on account of belonging to the *tantalite* family—called after Tantalus, Niobe, and Pelops, in heathen mythology.

Solutions containing niobic acid become of an orange red, when tincture of galls is added : but those containing tantalic acid, of a clear yellow colour. A slip of zinc, introduced into solutions, which contain niobic acid—and also free hydrochloric acid—produces, first a blue, then a brown tint, and lastly, a brown precipitate : but with salts of tantalic acid, in the same circumstances, white tantalate of zinc is gradually thrown down. Tantalic acid is known also by the precipitates it affords [487] with ferrocyanide, and sulphocyanide of potassium. Niobate is distinguished from tantalate of soda, by being soluble.

590. OSMIUM :*—*ymb.* Os. ; *equiv.* 99·72. It was discovered by Tennant in 1803. Particles of it, combined with iridium, are found, mechanically mixed with the ore containing platinum, rhodium, and palladium : and it is obtained, from the pulverulent residue of platinum ore—after the platinum, rhodium, and palladium have been removed, by digestion with aqua regia—by grinding it to a fine powder, and heating it to redness, along with the third of its weight of nitre, in a silver crucible, until it becomes pasty. The peculiar odour of the oxide of osmium will then be perceived : and the soluble parts, which contain it in combination with potash, being dissolved with as little water as possible, the solution is acidulated, and poured into a retort, along with its own weight of water : and then distilled rapidly, as long as the odour is perceptible. The osmic acid, which will be collected on the sides of the receiver, as a white crust, will, on melting, run down in drops, and form, in the watery solution, a liquid flattened globule, which crystallizes, as the receiver cools. Metallic osmium may be precipitated from the solution of this acid, by any of the metals—except gold, or silver : or, by agitating with mercury, dissolving the resulting protoxide of that metal, with hydrochloric acid, and driving off both mercury, and calomel, by raising the temperature.

591. Osmium, thus obtained, is a black powder ; but with heat, and compression, it becomes like platinum—though less brilliant. When most dense, its specific gravity is 10·0. It is easily pulverized. While in the form of powder, it burns in the atmosphere, if it is heated to redness : and it may be oxidized by nitric acid :—but, after it has been ignited, it loses these characters.

592. Osmium forms, with oxygen, protoxide (OsO ; 107·72) ; sesquioxide (Os_2O_3 ; 223·44) ; deutoxide (OsO_2 ; 115·72) ; teroxide (OsO_3 ; 123·72) ; and osmic acid (OsO_4 ; 131·16), which is volatile, and though it has not an acid reaction, combines with bases. With chlorine, protochloride (OsCl ; 135·19) ; sesquichloride (Os_2Cl_3 ; 305·85) ; bichloride (OsCl_2 ; 170·66) : and terchloride (OsCl_3 ; 06·13). With sulphur, protosulphuret (OsS ; 115·72) ;

* *Osmē*, an odour, *Gr.*, from the irritating nature of its acid.

sesquisulphuret (Os_2S_3 ; 247.44); bisulphuret (OsS_2 ; 131.72): and tersulphuret (OsS ; 147.72), &c.

593. Salts of osmium are recognised, by heating them on platinum foil, with carbonate of soda:—osmic acid will be evolved, and easily known, by its action on the eyes and lungs. They afford, with sulphuretted hydrogen, and hydrosulphuret of ammonia, a brown black precipitate. Solutions containing osmic acid combined with alkalis, become, when tincture of galls is added, of a colour which being at first purple, changes to deep blue: and is made, by sulphurous acid, to pass through the shades of yellow, orange, brown, green, and blue—from sulphates of the different oxides being produced, the last tint being caused by a compound of oxide and sesquioxide. Osmium is reduced to the metallic state, not only by many metals, but also by several organic compounds.

594. PALLADIUM:—*symb.* Pd; *equiv.* 53. It was discovered by Wollaston in 1803: and is found in ores of platinum. When the latter has been separated from its solution in aqua regia, by means of sal-ammoniac, and filtration, the residual liquor is neutralized with soda: after which the palladium is thrown down, by cyanide of mercury. The resulting cyanide, being decomposed by ignition, palladium is obtained in the metallic state.

595. It is like platinum, but harder. Its specific gravity is 11.5. It is malleable, and ductile. It is more fusible than platinum. Heated below ignition, its surface becomes covered with a blue, or green, coating of suboxide: but, when the temperature is raised, the metal is reduced, oxygen being driven off. Palladium burns, with the emission of sparks, under the oxy-hydrogen blow-pipe. Like iron, it welds. It is insoluble in sulphuric, or hydrochloric acid: but is soluble in nitric acid, and aqua regia.

596. Palladium forms, with oxygen, suboxide (Pd_2O ; 114); oxide (PdO ; 61); and deutoxide (PdO_2 ; 69). With chlorine, protochloride (PdCl ; 88.47): and bichloride (PdCl_2 ; 123.94). With sulphur, sulphuret (PdS ; 69), &c.

The oxides of palladium produce beautiful red coloured salts, from which the metal itself is precipitated, in the metallic state, by sulphate of the protoxide of iron, by sulphurous acid, by a formiate, and by nearly all the metals but gold, silver and platinum.

597. Palladium is known, by giving, with potash, a yellowish brown basic salt, soluble in excess. With iodide of potassium, a black precipitate. With sulphuretted hydrogen, or hydrosulphuret of ammonia, a black precipitate, soluble in the hydrosulphuret. With cyanide of mercury, or of potassium, a yellowish white cyanide, soluble in a large quantity of hydrochloric

* From the planet Pallas.

acid. Palladium may, by means of sulphuretted hydrogen, be separated, from all the metals, not precipitated by that re-agent. The resulting sulphuret is changed, by heat, into basic sulphuret, soluble in hydrochloric acid. Chloride of palladium gives, with ammonia, a flesh red precipitate ($\text{PdCl} + \text{NH}_3$) soluble in excess.

598. PELOPIUM: *—*symb.* *Pe*. It was shown, by Rose, to exist, in combination with tantalum and niobium; and is obtained, by passing chlorine over a mixture of niobic acid and powdered charcoal, raised to a red heat:—chlorides of niobium, and pelopium are produced; and the latter sublimes into a distant part of the tube. The chloride of pelopium being then saturated with ammoniacal gas, and ignited, water, hydrochloric acid, and metallic pelopium are the results. Very little is known, regarding this metal.

599. PLATINUM: †—*symb.* *Pl*; *equiv.* 98·84. It was discovered by Wood, Assay-master of Jamaica, in 1741: and occurs only in the metallic state, combined with other metals. It is obtained pure in commerce.

Platinum is not so brilliant as silver. Its specific gravity is 21·5.—It is, therefore, the heaviest of all metals, and, indeed, of all known substances. It is malleable, ductile and, like iron, capable of being welded. It melts under the oxy-hydrogen blow-pipe. It is not affected by the atmosphere: but it is slightly oxidized when nitre, or potash, are melted upon it, or when some metals are reduced, in contact with it. It is dissolved only by aqua regia, and hydrofluoric acid.

600. Platinum forms, with oxygen, protoxide (PtO ; 106·84); and deutoxide (PtO_2 ; 114·84). With chlorine, protochloride (PtCl ; 134·31); and bichloride (PtCl_2 ; 169·78). With iodine, protiodide (PtI ; 225·69); and binodide (PtI_2 ; 352·54). With sulphur, protosulphuret (PtS ; 114·84); and bisulphuret (PtS_2 ; 130·84), &c.

601. *Bichloride of platinum* (PtCl_2) may be obtained, by dissolving the metal in nitro-muriatic acid, evaporating the solution to dryness in a water bath, and redissolving in water.

602. Platinum, in a solution which is not too dilute, and, in the presence of free hydrochloric acid, gives, with potash, ammonia, chloride of potassium, or sal-ammoniac, a yellow crystalline precipitate, the potassio-chloride ($\text{KCl} + \text{PtCl}_2$), or ammonio-chloride ($\text{NH}_4\text{Cl} + \text{PtCl}_2$), of platinum, which is soluble in excess, the temperature being raised, and produces [193] spongy platinum, when heated to redness.—If the latter is obtained from the ammonio-chloride, hydrochloric acid is

* See note page 515.

† *Platina*, little silver, from *plata*. silver, *Sp*.—on account of its resemblance to that metal. Its name, according to others, is derived from that of the river Plate, in South America, near which it is found.

formed by the chlorine combining with hydrogen, derived from some of the ammonia, which is decomposed. Sulphuretted hydrogen, and hydrosulphuret of ammonia, throw down, in acid, and neutral solutions, a blackish brown bisulphuret, which dissolves—slowly, at ordinary temperatures, but immediately, if heated—in aqua regia, or in hydrosulphuret of ammonia, containing an excess of sulphur [253]. Protochloride of tin changes peroxide of platinum in solution, to protoxide—which may be known by iodide of potassium, in excess, imparting to the liquor a red colour, when a drop of nitric acid, or of chlorine water is added. It gives, with chloride of platinum, a chocolate coloured precipitate, or, when the quantity of platinum is small, a deep reddish brown solution, the bichloride of platinum being altered to protochloride. Iodide of potassium gives a corresponding iodide, in the form of a black precipitate soluble in excess—the solution being of a rich crimson colour.

Platinum is thrown down from its solutions, in the metallic state, as a black powder termed “platinum black,” by immersing in them a slip of zinc, and boiling the precipitate, for a little while in hydrochloric acid. This substance, like spongy platinum, causes gases to unite. It is useful, also, in organic chemistry.

603. Platinum, when perfectly clean, has the property of making gases [193] combine.—It is rendered sufficiently free from foreign substances, by fusing upon it some caustic potash, washing off the alkali with distilled water, then dipping the platinum in hot oil of vitriol, and again washing it. Touching the clean surface, exposing it to the atmosphere for a few days, &c., diminish, or altogether destroy its power:—the same effect is produced by small quantities of olefiant gas, sulphuretted hydrogen, carbonic oxide, and of other gases.

604. Since platinum is highly important to the chemist, and is, at the same time, a very expensive substance, the following suggestions, regarding the mode of using it, will not be inappropriate—

It should not be employed in fusing the caustic alkalies, nor in calcining lime, barytes, or strontites: nor in heating alkaline nitrates—since the affinity of the alkali, for oxide of platinum causes a considerable oxidation, on its surface. The alkaline sulphurets, or other sulphurets mixed with charcoal, are, in similar circumstances, still more injurious. A metal in the state of *regulus** injures platinum, since the latter combines with it at the temperature of fusion. It is completely perforated, by a single drop of bismuth, tin, or lead. Gold, silver,

* From *rex*, a king, *Lat.* The metallic matter, separated from other bodies by fusion, was so named by the alchymists, who expected it to contain gold—called by them [358: note] the king of metals.

or copper, below the temperatures of fusion, do not affect platinum. The oxides of metals, which lose their oxygen, at a white heat, cannot be raised to that temperature, in platinum; for the latter would combine with the reduced metal. The oxides of bismuth, copper, lead, and nickel, at a high temperature, are very injurious to platinum; but, at a moderate, they do not act upon it.—The student should bear in mind, that clay-slate generally contains small quantities of copper. Phosphorus, and phosphoric acid, mingled with combustible matters, would form phosphuret of platinum. Silicon, and carbon, combine with platinum:—hence the latter must not be brought in contact with wood, at a high temperature. The soot, from the smoke of a lamp, diminishes the weight of platinum; and it is found, when examined, to contain that metal—which is sometimes even perforated by it. This injurious effect is increased by the presence of copper—which, also, may be detected in the soot: but it is not so bad as might be anticipated, from the fact that spongy platinum, when mixed with powdered charcoal, melts in a platinum crucible. Since chlorine acts on platinum, aqua regia must not be put in contact with it; nor must any mangiferous substances [328] be dissolved in it, with hydrochloric acid. Hence, when, during the analysis of a mineral, the mass obtained by fusion with an alkaline carbonate, is green or black, hydrochloric acid must be added to it in a *glass* vessel—in which also the evaporation must be continued, until the odour of chlorine is no longer perceptible. Polished platinum is less easily affected than that which is rough:—the latter, even after the foreign substance has been removed, is injured by being merely heated to redness. When, therefore, the surface has, from any cause, lost its smoothness, it must, before it is used, be flattened, and polished, with a hammer. The stains left on platinum, by certain substances, may, with care, be taken away without doing any harm, by washing it with sand, the particles of which are round. When the stains are of a more permanent character, the surface may be cleaned by a little vitrified borax.

605. Gold may be used for repairing holes, or cracks, in platinum; but a high heat would melt that metal, which would then combine with the platinum. It is better, therefore, to put upon the crack, &c., several layers of a varnish, formed of oil of turpentine, and platinum—obtained, by mixing the ammonio-chloride [602] with twice its weight of common salt, heating the mixture to redness, and then washing away the common salt from the reduced metal, with water. When the different layers of the varnish are well dried, the flame of a spirit lamp, urged with oxygen, is to be thrown upon it:—and, to avoid a loss of heat, by radiation during the process, the interior of the vessel to be repaired, should be filled with a

piece of porous charcoal, of the proper shape; and the outside should be covered with another piece—an aperture, to admit the flame, being left opposite to the part which is being repaired, and which is to be alternately hammered, and heated, until all trace of the injury has disappeared.

606. To preserve a platinum crucible, from the impurities generally contained in ordinary fuel, it is well, during an operation which requires a high temperature, to keep it within a small Hessian crucible.

607. POTASSIUM:—*symb.* K;† *equiv.* 39·12. It was discovered in 1807, by Davy, who obtained it, from caustic potash, by means of the galvanic battery. It may be procured, by igniting “cream of tartar” ($2\bar{T} + KO$) in a covered crucible. The tartaric acid is decomposed: and the residue, which consists of carbonate of potash, and carbon in a state of minute division, is to be well mixed, while hot, with coarsely powdered charcoal—that it may be sufficiently porous, to allow the escape of gases which will be generated—and placed in an iron mercury bottle [82]. The latter is then to be laid on its side, in a wind furnace—a communication having been formed, by an iron tube, between it, and a vessel partly filled with rectified naphtha, and surrounded with ice. The gases pass off, under partitions fixed in the receiver: and the whole is so arranged, that the tube may, from time to time, be cleaned with an iron wire, to free it from a compound of potassium and carbonic oxide, which is formed within it during the process—and which, indeed, causes a waste of half the potassium. Atmospheric air must not be allowed to enter the apparatus. When the bottle is white hot, the potassium distils over. Potash and the carbonic acid, in combination with it, are decomposed: and the atom of oxygen, liberated from each, unites with carbon, carbonic oxide being formed. $(CO_2 + KO) + 2C = K + 3CO$. The potassium obtained in this way, may be purified from the compound of carbonic oxide and potassium, and the carbon, associated with it, by redistillation from cast-iron retorts, out of which the atmospheric air has been expelled with vapour of naphtha.

608. Potassium is of a bluish white colour. Its specific gravity is 0·865.—It is therefore lighter than water, and, by consequence, floats upon that fluid. At ordinary temperatures, it is soft, like wax; at 32°, it is brittle, and crystallizes in cubes; at 70°, it is pasty; at 150°, a liquid; and it boils at a dull red

* So called, because it is the base of *potash*—which derives its name from the “pots” in which it was originally obtained, from the ashes of vegetables.

† From *hali*, the name of a plant, whence the Arabs obtained alkalies. The particle “al,” was intended, by them, to signify that the alkali is superior, in its properties, to the plant itself.

heat, the vapour being green. In the air, it becomes immediately tarnished, by a coating of oxide:—and must, therefore, to exclude the oxygen, be preserved in vacuo, or in vessels of naphtha. Heated in the atmosphere, it burns with a bluish flame. It decomposes water, or even ice, with great rapidity, potassiu-retted hydrogen—which takes fire spontaneously—being evolved. During the process, the potassium moves about rapidly, on the surface of the water: and the resulting globule of caustic potash, when it has cooled a little, suddenly combines with and is dissolved in the water—a loud report being produced. On account of its great affinity for oxygen, potassium, as we have seen more than once, enables the chemist to deoxidize metals, otherwise very difficult to be reduced. At high temperatures, it has a less affinity for oxygen than iron, or carbon: which is not the case when the heat is lower.

609. Potassium forms, with oxygen, protoxide (KO ; 47·12), ordinarily called “caustic potash,” “potash,” or “potassa,” and by the Germans “kali:” and peroxide (KO_2 ; 63·12). With chlorine, chloride (KCl ; 74·59). With iodine, iodide (IK ; 165·97). With bromine, bromide (KBr ; 119·09). With fluorine, fluoride (KF ; 57·98). With sulphur, protosulphuret (KS ; 55·12); bisulphuret (KS_2 ; 71·12); tersulphuret (KS_3 ; 87·12); tetrasulphuret (KS_4 ; 103·12); and pentasulphuret (KS_5 ; 119·12). With cyanogen, cyanide, &c.

610. *Potash.* The aqueous solution of potash, or the “aqua potassæ”* of pharmacy, may be obtained, by decomposing carbonate of potash with an equal weight of slaked lime. The potash should be previously dissolved in ten times its weight of hot water: since a solution of carbonate of potash, which does not contain at least six times its weight of water, is not decomposed by lime; but, on the contrary, a strong solution of caustic potash decomposes carbonate of lime—carbonate of potash being formed, and caustic lime liberated. When the decomposition of the carbonate of potash is effected, at ordinary temperatures, the resulting carbonate of lime is very light, occupies a large space, and is not so easily removed. The solution, therefore, containing the lime is to be boiled strongly in a clean iron vessel, for ten minutes; and, after it has rested for a while, the supernatant solution of caustic potash may be decanted off from the carbonate of lime, which has subsided. If the potash is rendered impure by the presence of lime, air from the lungs, blown through it, will precipitate carbonate of lime: if it contains undecomposed carbonate of potash, the addition of an acid will produce effervescence.

611. A solution of potash is strongly alkaline, very acrid, and corrosive. It acts energetically, on many organic substances:

* Water of potash. *Lat.*

and has, when rubbed between the fingers, a peculiar feel, on account of forming a kind of soap with the cuticle. It has an exceedingly strong affinity for carbonic acid :—hence, that gas may, by means of it [263], be removed from others. It absorbs carbonic acid rapidly from the atmosphere, and must, therefore, be kept in well-stopped green [393] glass bottles. It is the basis of soft soaps. It dissolves the oxides of antimony, arsenic, cobalt, lead, manganese, molybdenum, nickel, tellurium, tin, tungsten, and zinc : also many animal substances.

612. *The protohydrate of potash* is obtained, by evaporating the aqueous solution in a silver, or clean iron vessel, to the consistence of oil : then pouring it out ; dissolving it in alcohol, to free it from any oxide of iron, chloride of potassium, carbonate or sulphate of potash, which it may contain : and again evaporating. To prevent carbonic acid being absorbed from the atmosphere, the process must be carried on rapidly :—the vapour, which rises from the fluid, will prevent the atmospheric air from coming in contact with it. If carbonate of potash is present, it will not melt with the hydrate, and may be removed, with a silver skimmer. When the potash is fused perfectly, it is to be poured out on clean iron, &c. : and, being broken in pieces, it must be put into a well-stopped bottle, as soon as possible. Its composition is $KO + HO$. On account of destroying animal substances, it is used in medicine, as a caustic, under the name of “potassa,” or “potassa fusa.”* It is very deliquescent :—dissolved in water, and crystallized, its composition becomes $KO + 5HO$.

613. *Carbonate of potash* ($CO_2 + KO$), a salt of great utility in chemical analyses, &c., may be conveniently obtained, by exposing the bitartrate ($2T + KO$) to a high heat, which decomposes the vegetable acid, carbonate of potash being formed. The latter may be rendered perfectly pure, by solution, filtration — to separate the charcoal — and evaporation. The result is a granular mass, formerly called “salt of tartar.” When crystallized, its composition is $CO_2 + KO + 2Aq$. It is nearly insoluble in alcohol. Since common cream of tartar almost always contains tartrate of lime, when the carbonate is intended for delicate or important purposes, it is proper to form the bitartrate, by saturating caustic potash with tartaric acid.

614. *Sulphate of potash* ($SO_3 + KO$), may be obtained, by neutralizing carbonate of potash, with sulphuric acid.

615. *Chlorate of potash* ($ClO_3 + KO$), which is important in commerce, on account of its being used extensively in the manufacture of matches, and is very useful to the chemist, in a variety of ways, may be formed, by passing a current of chlorine, through a strong solution of caustic potash

* Fused potash. *Lat.*

(KO). Chloride of potassium (KCl), and hypochlorite of potash ($ClO + KO$) are the results. $2KO + 2Cl = KCl + (ClO + KO)$. When the liquor, in which these are contained, is boiled for some time, the hypochlorite is decomposed, oxygen being given off, and chloride of potassium, along with chlorate of potash, being formed. $9(ClO + KO) = O_{12} + 8KCl + (ClO_3 + KO)$. The chlorate may be easily separated from the chloride, as it crystallizes sooner, if the liquid is concentrated. Chlorate of potash exhibits, in a striking manner, the facility with which chloric acid yields its oxygen. When placed on red hot charcoal, it deflagrates like nitre. It was, for a considerable time, used by the French, as a substitute for nitre, in the manufacture of gunpowder: but the explosive nature of a mixture containing this salt and sulphur [122], caused several lives to be lost. It forms a gunpowder, stronger than the ordinary kind:—for, when nitre is one of the ingredients, the effect is diminished, by some of the carbonic acid [240] uniting with the potash. Too much caution cannot be observed, in experiments, or processes, in which chlorate of potash is employed.—Indeed the greatest care must be taken, whenever an explosion may happen, either by accident, neglect, or inadvertence. Many of the substances I have occasion to mention, should be avoided, by the inexperienced: and I notice some of them, with scarcely any other object than to prevent the accidents which might occur from their unintentional production.

616. Lucifer matches are made, by dipping the ends of small pieces of wood, &c., in melted sulphur: and then, in a mixture containing chlorate of potash, along with sulphur and charcoal, with sulphuret of antimony, or with cinnabar (HgS), and made into a paste, with gum arabic. It is necessary to dip the match, previously, in the sulphur, or the combustion would be too rapid to ignite the wood, &c. Stearine is sometimes used, instead of sulphur, for coating the match; but it does not always inflame. *Noiseless* lucifer matches contain nitre, and phosphorus:—the phosphorus has a very great affinity for oxygen [321]: the nitre contains a large quantity of it [238]: and a very slight cause—friction, for instance—is sufficient to make them combine. According to Böttger, sixteen parts gum arabic, nine parts phosphorus, fourteen parts nitre, and sixteen finely divided peroxide of manganese, form an excellent composition for coating the sulphur. To avoid danger, they must be worked up with water.

A mixture of chlorate of potash, and sulphur, was formerly used for the percussion caps of detonating guns; but fulminate of the suboxide of mercury is now employed, for the purpose.

617. *Antimoniate of potash* ($SbO_3 + KO$), may be made by

mixing one part antimony of commerce, with four parts nitre in powder, and throwing the mixture by little at a time into a crucible heated to dull redness. When the pasty mass has been kept stirred for about half an hour, it is cooled, washed with water so as to dissolve out the nitrate and nitrite of potash, and heated to full redness for half an hour in a Hessian crucible, along with somewhat less than half its weight of carbonate of potash. After having cooled, it is digested with twenty parts warm water, and filtered, when cold.

618. *Chromate of potash* ($\text{CrO}_3 + \text{KO}$), may be obtained, by dissolving the bichromate of commerce in water, and adding carbonate of potash, until there is a slight alkaline re-action. Crystals of the neutral chromate of potash, will separate from the resulting yellow liquid, when it is concentrated.

619. *Chloride of potassium* may be obtained, by neutralizing carbonate of potash [613], with hydrochloric acid.

620. *Iodide of potassium* (IK) may be obtained, by adding iodine to a hot solution of caustic potash, until the latter is neutralized. The result is iodide of potassium, and iodate of potash. ($\text{IO}_3 + \text{KO}$):— $6\text{KO} + 6\text{I} = 5\text{KI} + (\text{IO}_3 + \text{KO})$. On evaporating the solution containing these compounds, to dryness, and bringing the residue to a gentle red heat in a platinum crucible, the iodate gives off its oxygen, and becomes iodide of potassium.

621. *Sulphuret of potassium* (S_2K) may be obtained, as a reagent, by fusing carbonate of potash with its own weight of sulphur. The carbonic acid is driven off, and a mixture of sulphate and sulphuret is left behind.

622. *Cyanide of potassium* ($\text{K.C}_2\text{N}$) may be formed, by fusing, at a bright red heat, in a covered iron crucible, eight parts roasted yellow prussiate, with three parts very dry carbonate of potash, until it becomes calm and clear: then pouring the melted mass carefully into a warm dish: and when cold, breaking it in pieces. It must be kept in a well-stopped bottle, and be dissolved according as it is required.

623. Potassium is known, in neutral, and acid solutions, by giving, with bichloride of platinum, the double chloride [602], distinguished from the analogous ammonio-chloride, by not being volatilized at a red heat. Before adding the chloride of platinum, a minute quantity of hydrochloric acid should be poured into the liquid to be tested; and it should be evaporated to dryness, at the temperature of 212° :—after this, a little cold water being added, the double chloride will appear in small bright yellow crystals. Tartaric acid precipitates potassium, from neutral, or alkaline solutions, as a white granular crystalline precipitate the bitartrate of potash, which subsides rapidly. If the solution is alkaline, the tartaric acid must be added, until there is an acid reaction. When the

solution is dilute, the precipitate does not form immediately; but its formation is accelerated, by violent motion. Acid solutions, before being tested, must be neutralized with soda, or its carbonate. The bitartrate of potash is distinguished from that of ammonia, by being more insoluble: also, the salts of ammonia are all volatilized by a red heat—with, or without decomposition. Since ammonia [254] gives with bichloride of platinum, and tartaric acid, similar precipitates, ammoniacal salts should be removed by ignition, before testing for potash. Alcohol, containing a salt of potash, burns with a violet flame unless soda is present.

624. If a salt of potash is attached to a bit of platinum wire, and held in the inner flame of the blow-pipe, unless soda is present, the outer flame acquires a violet tint.—This arises from the production of potassium, and its subsequent oxidation. The glass formed under the blow-pipe, with nickel and borax [587], which should be brownish, becomes, if potash is present, of a blue colour.

625. RHODIUM: *—*ymb. R*; *equiv. 52.2*. It was discovered by Wollaston, in 1803: and is found in combination with platinum, and palladium—being dissolved out along with them, with aqua regia. After most of the platinum has been thrown down by sal-ammoniac, and all the palladium, by cyanide of mercury [594], and both are removed, hydrochloric acid is to be added: and the solution is to be evaporated to dryness, to decompose the excess of cyanide of mercury, and change it into a chloride. The residue must then be reduced to a fine powder, and washed with alcohol, specific gravity 0.837—which dissolves the double chlorides of sodium and platinum, of sodium and iridium, of sodium and copper, and of sodium and mercury, and leaves the double chloride of sodium and rhodium, in the form of fine red powder. The latter being washed with alcohol, is decomposed, by gently heating it in a current of hydrogen: and the reduced rhodium is separated from the chloride of sodium, with which it was combined, by washing with water.

626. Rhodium, thus obtained, is a black powder; but, when rendered coherent by pressure, it is white, and has a specific gravity of 11.0. It is hard, and very brittle. Alloyed with steel [529], copper, lead, or platinum, it dissolves along with them in aqua regia; but, when quite pure, it is insoluble in that fluid, even at a boiling temperature. It combines with every metal upon which the experiment has been made, except mercury. A sixth part of it renders gold much less fusible, but does not sensibly alter its colour.

627. Rhodium forms, with oxygen, protoxide (RO ; 60.2): peroxide (R_2O_3 ; 128.4); and also, it is probable, complex

* *Rhodon*, a rose. *Gr.*:—from the colour of its solutions.

oxides, resembling those of iron, and manganese. It forms, with chlorine, protochloride (RuCl ; 87.67); and perchloride (Ru_2Cl_9 ; 210.81), &c.

628. The most important of the salts of rhodium are those of the sesquioxide. They are known, in solution, by giving with potash, after protracted digestion, a greenish yellow precipitate; with ammonia, and carbonate of ammonia—after some time—a yellow precipitate consisting of sesquioxide of rhodium and ammonia, soluble in hydrochloric acid. With sulphuretted hydrogen, and hydrosulphuret of ammonia—also, after some time—a dark brown precipitate.

629. The haloid salts of rhodium are red; the oxysalts, yellow, red, or brown.

630. All the salts of rhodium, when heated, are decomposed by dry hydrogen, the metal being reduced.

631. RUTHENIUM:—*symp.* Ru ; *equiv.* 52.1. It was discovered by Professor Clauss; and is obtained from platinum ore—after the platinum, iridium, and osmium are removed—by fusing it with nitre, and keeping it at a white heat, for two hours, in a Hessian crucible. Then, while the mass is still hot, it is taken out with an iron spatula: and, after cooling, is reduced to a coarse powder. Distilled water being next added, and the whole having been allowed to rest, the supernatant perfectly clear, dark yellow liquid is decanted—but not filtered, since, the filtering paper would decompose it. Afterwards nitric acid is cautiously added, until the alkaline reaction disappears:—this precipitates the oxide of ruthenium, potash, and silicic acid, as a black powder, and the chromate of potash remains in solution. The precipitate having been dissolved in hydrochloric acid, and the solution evaporated until the silex separates, it is diluted with water, and filtered.—It cannot be evaporated to dryness, to separate the silex more completely: for the chloride of ruthenium would then be changed into insoluble protochloride.

632. Ruthenium resembles iridium in appearance. Its specific gravity is 8.6. Heated in atmospheric air, it combines with oxygen.

633. Ruthenium forms, with oxygen, protoxide (RuO ; 60.1); sesquioxide (Ru_2O_3 ; 128.2); peroxide (RuO_2 ; 68.1); and ruthenic acid (RuO_3 ; 76.1). It combines with sulphur, &c.

634. Ruthenium, unlike all the other platinum metals, is precipitated by ammonia, as a black oxide, from the aqueous solution of its chloride, at *ordinary temperatures*.—This may be reduced, by passing a current of hydrogen over it, at a red heat.

Metallic ruthenium is precipitated as a black powder, when a slip of zinc is inserted, in the orange coloured solution of its chloride, acidified with hydrochloric acid. The solution will

be indigo blue, until all the metal is thrown down : after which, it will be colourless.

635. SILVER :—*ymb.* Ag. ; * *equiv.* 107·92. This metal was known to the ancients. It is found native : also as a sulphuret, and in combination with various metals :—lead almost always contains it. If uncombined, and in a finely divided state, it is washed out by mercury—from which it is separated by heat. It is obtained, from the sulphuret, by roasting it, with common salt, in a reverberatory furnace.—Chloride of silver and sulphuret of sodium are formed. $\text{AgS} + \text{NaCl} = \text{AgCl} + \text{NaS}$. The chloride being put, along with water iron and mercury, into barrels which are made to revolve by machinery, chloride of iron is formed, and the reduced silver is dissolved by the mercury. The mass is then squeezed through leathern bags, the pores of which allow the uncombined mercury to pass through, while the amalgam of silver and mercury is retained. As in the former instance, the mercury is driven off by heat.

636. When silver is procured from galena [541], the combination of lead and silver being melted, and slowly cooled, the lead, which requires a higher temperature for fusion than its combination with silver, solidifies first, and is removed. By repeating this process, much of the lead is got rid of. The remaining silver and lead, is then put into a porous dish, made of burnt bones, called a *cupel*, and is heated to redness, a current of air being driven across the surface of the metal. This changes the lead into litharge, which is partly absorbed by the cupel, and partly blown away.—When the silver becomes suddenly brilliant, it is known to be quite pure. Mercury or copper, also, if present, would be oxidized, and removed, during the process.

637. Pure silver may be obtained, for chemical purposes, by precipitating it from its solution, by means of clean copper.

638. Silver is the whitest of all the metals, and is exceeded in brilliancy, only by polished steel. Its specific gravity is 10·474. It is very malleable, since it may, without breaking, be hammered into leaves, very little more than the 160000th of an inch in thickness—which is, however, one third more than that of gold leaf. Unlike the latter, silver leaf does not transmit light, when pure. Silver is very soft ; but it is hardened, by admixture with copper :—222 parts silver, and 18 copper, constitute standard silver of the mint ; but that used for ordinary purposes, is less pure. It melts at 1873° Fahrenheit : and, if pure, absorbs oxygen during fusion, but gives it out again, when solidifying—which causes the surface to be granulated. Exposed to the atmosphere, however moist, it is not oxidized ; but it is very soon covered with a coating of sulphuret—on account of

* From *argentum*, silver. *Lat.*

the sulphuretted hydrogen, generally present in the air. A small wire, or a thin leaf, of silver will burn in the oxy-hydrogen flame. When ignited, by means of the galvanic battery, it emits greenish white sparks. Silver is soluble in nitric, and by the aid of heat, in sulphuric acid.

639. It forms, with oxygen, suboxide (Ag_2O ; 223·84); and oxide (AgO ; 115·92). The latter, combined with ammonia, forms a black powder ($3\text{AgO} + \text{NH}_3 + \text{Ag}$)—the ammoniuret of silver, which the slightest shock, or friction, causes to explode with great violence. Silver forms, also, peroxide (AgO_2 ; 123·92). It forms, with chlorine, chloride (AgCl ; 143·39).—This compound, which is often produced in testing [333, &c.], will yield its metallic silver, if placed along with some clean iron, or zinc, in a small quantity of water—a little sulphuric, or hydrochloric acid being added. Chloride of zinc—or iron—and pure silver are the results. Silver forms, with iodine, iodide (AgI ; 234·77). With bromine, bromide (AgBr ; 187·89). With sulphur, sulphuret (AgS ; 123·92), &c.

640. *Nitrate of silver* ($\text{NO}_3 + \text{AgO}$). It may be obtained by dissolving standard silver in nitric acid; then converting all the copper present into black oxide, by evaporation, and the continued application of heat.—When this has been completely effected, water of ammonia added to a drop of solution of the salt will not cause a blue tint. The fused mass is to be dissolved in water, and filtered. Nitrate of silver is an extremely corrosive substance: it rapidly destroys animal tissues, and is much used in surgery, &c. When, fused and cast in moulds, so as to form small sticks, it is termed “lunar* [550; note] caustic.” It throws down hydrochloric, hydriodic, hydrobromic, hydrocyanic, hydrosulphuric, iodic, periodic, and bromic acids, from their neutral solutions.

641. *Ammonio-nitrate of silver* ($\text{NO}_3 + \text{NH}_4\text{O} + \text{NH}_2\text{Ag}$), is obtained, by cautiously dropping water of ammonia, into a solution of nitrate of silver, until the precipitate, at first formed, is redissolved.—It must be prepared every time it is required.

642. Silver, in solution, is known, by giving, with potash, and ammonia, a light brown oxide, soluble in ammonia:—the presence of ammoniacal salts diminishes the precipitate, or altogether prevents its formation. It gives, with the alkaline carbonates, a white precipitate, soluble in carbonate of ammonia. With hydrochloric acid, and the soluble metallic chlorides, a white chloride—soluble in ammonia, and changed, by the action of light, to violet, and then black. With iodide of potassium, a canary yellow precipitate. With chromate of potash, a rich brown. With sulphuretted hydrogen, and hydrosulphuret of ammonia, a brown black sulphuret—soluble in, and

* *Luna*, the moon. *Lat.*

decomposed by boiling nitric acid, sulphur being deposited. With ferrocyanide of potassium, a white precipitate: with ferridecyanide of potassium, a reddish brown, and, with chromate of potash, a rich brown. The salts of silver, when mixed with carbonate of soda, and placed on charcoal, are easily reduced by the blow-pipe. Most metals precipitate silver, in the metallic state:—mercury, however, effects this but slowly, giving rise to the symmetrical product, termed “the tree of Diana.” Silver is precipitated, in the metallic state, also, by the sulphites: by sulphate of the protoxide of iron—which is peroxidated; and, by protochloride of tin, which resolves itself into bichloride, and metallic tin:—the latter reduces the oxide of silver, by combining with its oxygen.

643. SODIUM:—*symb.* Na ; * *equiv.* 22·97. It was discovered by Sir H. Davy, in 1807: and is found in combination, most abundantly—being one of the constituents of common salt, &c. It may be obtained, in the same way as potassium [607]: but more easily, since it does not form a compound, with carbonic oxide; nor does the process require so high a temperature.

644. Sodium is a brilliant white metal. Its specific gravity is 0·972.—Like potassium, therefore, it floats upon water. At ordinary temperatures it may be moulded with the fingers. It melts at 200° , and is vaporized, by a red heat. It is soon oxidized by the air: and immediately by water, hydrogen, temporarily combined with soda, being evolved.—If it is allowed to move about in that fluid, the gas produced does not take fire spontaneously, unless some oil of vitriol has been previously added. When the globule is kept in one place, by fastening it to the side of the vessel, or thickening the water, with gum or starch, the fluid becomes heated, and the action is then so energetic, that the gas ignites.

645. Sodium forms, with oxygen, protoxide (NaO ; 30·97), ordinarily called “soda,” and by the Germans, *natron*: also, peroxide (Na_2O_3 ; 69·94). With chlorine, chloride (NaCl ; 58·44) or “common salt,” which is insoluble in absolute alcohol, but is soluble, and with equal facility, in hot or cold water. With iodine, iodide (NaI ; 149·82). With bromine, bromide (NaBr ; 102·94). With fluorine, fluoride (NaF ; 41·83). With sulphur, sulphuret (NaS ; 38·97), &c.

646. *Soda* resembles potash very much; and may be obtained in solution [610], or as a hydrate [612], in the same way, as that substance.

647. *Carbonate of soda* ($\text{CO}_2 + \text{NaO}$) is manufactured, in large quantities, for the use of the soap boiler, &c., by adding sulphuric acid to common salt [355]: and heating the resulting sulphate to redness, along with charcoal—or coke—and carbon-

* From *natron*, the name of a native soda.

ate of lime. The oxygen of the sulphuric acid, forms carbonic oxide, with the carbon: and sulphuret of sodium, with the carbonate of lime, sulphuret of calcium and carbonate of soda. $(\text{SO}_3 + \text{NaO}) + 4\text{C} = \text{NaS} + 4\text{CO}$: then, $\text{NaS} + (\text{CO}_2 + \text{CaO}) = \text{CaS} + (\text{CO}_2 + \text{NaO})$.—The carbonate of soda is dissolved out, with water. Sometimes, the common salt is decomposed, by carbonate of ammonia; and, when the resulting carbonate of soda has been separated, the sal-ammoniac is reconverted into carbonate, by carbonate of lime. If this process is employed, the soda salt contains no sulphur: but ammonia is wasted. It is obtained pure very conveniently by heating the best commercial bicarbonate of soda to redness, for some time.

648. *Hyposulphite of soda* ($\text{S}_2\text{O}_2 + \text{NaO}$) may be made, by transmitting sulphurous acid, through a solution of bicarbonate of soda; and boiling the result with sulphur. Hyposulphite of soda is produced, and carbonic acid is evolved;— $(2\text{CO}_2 + \text{NaO}) + \text{SO}_2 + \text{S} = \text{S}_2\text{O}_2 + \text{NaO} + 2\text{CO}_2$.

649. *Sulphate of soda* ($\text{SO}_3 + \text{NaO}$) may be obtained, by neutralizing carbonate of soda, with dilute sulphuric acid.

650. *Phosphate of soda* ($\text{PO}_5 + 2\text{NaO} + \text{HO}$) may be formed, by adding carbonate of soda to soluble superphosphate of lime [320], as long as effervescence continues:—phosphate of lime is thrown down, and phosphate of soda remains in solution. The sulphate of lime, which also is present, causes carbonate of lime to be found in the precipitate, and sulphate of soda in the solution:—the latter is got rid of, by recrystallization. The crystals of this salt, without losing their form, abandon, it is probable, ten out of their twenty-four atoms of water, if exposed to the air.

651. *Microcosmic salt* or phosphate of soda and ammonia ($\text{PO}_5 + \text{NaO} + \text{NH}_4\text{O} + \text{HO}$) is formed, by dissolving in hot water, and mixing together, six parts of phosphate of soda, and one of sal-ammoniac. On cooling, crystals are produced, which effloresce in the air. They are freed from the chloride of sodium, which adheres to them, by recrystallization. And, being dried and pulverized, they may be preserved in a bottle, for use. This salt, when heated strongly, loses the elements of water and ammonia: and the residuum, which consists of monobasic phosphate of soda, and free phosphoric acid, is capable of fusing almost every chemical compound. Microcosmic salt produces results similar to borax (triborate of soda), but often more marked.

652. When the solution of a salt gives no precipitate with a carbonate, it is alkaline; and, if not recognised by the proper tests as ammonia [254] or potash [623], it must be a salt of sodium. Besides, antimoniate of potash, with the neutral or alkaline salts of sodium, affords a white crystalline antimoniate ($\text{SbO}_5 + \text{NaO}$), even if potassium also is present—which, however,

ought not to be the case. When the solution is dilute, it is formed very slowly: but its production is accelerated, by violent motion; and it will be perceived on the vessel, if of glass, wherever it is rubbed with a glass rod. Should the liquid to be tested contain carbonate of potash, the carbonic acid must previously be driven off, by hydrochloric acid. Acid solutions must be rendered slightly alkaline by potash: or the antimoniate of potash will be decomposed, hydrated antimonious acid, or bi-antimoniate of potash being precipitated. Tartaric acid produces a precipitate, only in highly concentrated solutions containing sodium: and the bitartrate which after some time, separates, is in the form of needles and columns—while bitartrate of potash is in the form of grains. If a small quantity of water is added to a salt of soda, and then alcohol, when the latter is ignited, the flame is a deep yellow, whether potash [623] is present or not. If a salt of soda, even when mixed with a large quantity of potash [624], is heated on a platinum wire in the inner flame of the blow-pipe, the outer flame is intensely yellow—on account of the combustion of the sodium, which is reduced by the inner flame.

653. STRONTIUM:—*symb.* Sr; *equiv.* 43·65. It was discovered by Davy, in 1807: and is obtained from the earth strontia—which greatly resembles baryta, and at first, was confounded with it—by the method used for obtaining barium [444].

Strontium is very like barium, but not so brilliant. It oxidizes in the air: and decomposes water, oxide being produced, and hydrogen being liberated.

654. Strontium forms with oxygen, protoxide (SrO ; 51·65) or “strontia,” used, in pyrotechny, for the production of a beautiful red fire: and peroxide (SrO_2 ; 59·65). With chlorine, chloride (SrCl ; 79·12). With iodine, iodide (SrI ; 170·50). With fluorine, fluoride (SrF ; 62·51). With sulphur, sulphuret (SrS ; 59·65), &c.

655. Strontium, in solution, is known by giving with sulphuric acid and the soluble sulphates, a more soluble precipitate ($\text{SO}_3 + \text{SrO}$) than barytes. It gives, with oxalic acid, a white oxalate ($\text{O} + \text{SrO} + \text{Ag}$)—and still more easily, if ammonia is added. It affords, with chromate of potash, on boiling, a yellow chromate ($\text{CrO}_3 + \text{SrO}$). Alkaline carbonates produce a white carbonate ($\text{CO}_2 + \text{SrO}$)—which is not completely precipitated, in acid solutions, until heat is applied. Solutions of gypsum cause a precipitate at once with barytes: but only after some time, with strontia. The latter may be separated from barytes, in the form of chloride, by adding an excess of hydrofluosilicic acid—which throws down, after being at rest for some hours, silico-fluoride of barium, the strontium being left in the solution. It may be separated from lime, when in the form of nitrate—

* Because the mineral containing it was found at Strontian, in Scotland.

excess of nitric acid being avoided—by evaporating to dryness, and digesting, for some hours, with absolute alcohol, which dissolves the nitrate of lime, but not the nitrate of strontia. When alcohol, in which soluble salts of strontia have been digested, is set on fire, the flame is of a carmine red colour. Chloride of strontium, heated on platinum wire, at the apex of the blue flame of the blow-pipe, tinges the entire flame of a deep crimson:—but this effect is prevented, by the presence of chloride of barium. As the assay fuses, the colour disappears—which distinguishes it from chloride of lithium.

656. TELLURIUM:—*ymb. Te*; *equiv. 64.25*. It was inferred to exist, by Müller, in 1782; but its existence was proved and its name was given to it, by Klaproth, in 1798. It has been found in the metallic state, combined with gold, silver, &c. in the gold mines of Transylvania—but only in small quantities. It is white, brilliant, and of a lamellated texture. Its specific gravity is 6.26. It crystallizes easily, is brittle, and as fusible as antimony. It burns under the blow-pipe, the flame being blue, bordered with green. It is rapidly oxidized by nitric acid; and gives to sulphuric acid a deep purple colour. It has a very close analogy to sulphur.

657. Tellurium forms, with oxygen, tellurous (TeO_2 ; 80.25), and telluric (TeO_3 ; 88.25) acids—both of which have different properties, according as they are in the hydrous, or the anhydrous state. It forms, with chlorine, chloride (TeCl_2 ; 99.72); and bichloride (TeCl_4 ; 135.19). With hydrogen, telluretted hydrogen (TeH 65.25) or hydro-telluric acid, &c.

658. Tellurium, as tellurous acid, is recognised, in solution, by giving, with the alkalies, and alkaline carbonates, a white precipitate—soluble in the latter, and in caustic potash. With sulphuretted hydrogen, a brown precipitate, soluble in hydro-sulphuret of ammonia. It is precipitated, in the metallic state, as a black powder, by sulphurous acid, and the alkaline sulphites; and by metallic zinc, &c.

659. TERBIUM:—*ymb. Tb*. The oxide of this metal was discovered by Mosander—being considered the principal ingredient in the second, or intermediate precipitate, obtained from yttria [499]. Nothing is yet known of its properties. Its oxide probably forms pale red salts.

660. THORIUM:—*ymb. Th*; † *equiv. 59.83*. It was discovered, by Berzelius, in 1829; and is obtained, from the chloride, by the action of potassium—the decomposition being accompanied by a slight detonation. After the mass has been washed, thorium is found, as a heavy powder of a deep leaden gray colour. Triturated in an agate mortar, it becomes of an iron gray; and has a metallic lustre. Thorium is not affected by water, either

* From *tellus*, the earth. *Lat.* † From *Thor*, a Saxon deity.

hot or cold, nor by caustic alkalies—even at a boiling temperature. Heated in the air, it burns as brilliantly as phosphorus does, in oxygen. Nitric acid affects it very little; sulphuric acid dissolves it slowly, but hydrochloric with great rapidity, hydrogen being disengaged.

661. Thorium forms, with oxygen, oxide (ThO ; 67·83) called “thorina,” the sulphate of which, unlike all other oxidized bodies, is precipitated by boiling, and redissolved by cooling. It forms compounds with chlorine, &c.

662. Thorina is thrown down from solutions of this metal, by the caustic alkalies, as a hydrate which rapidly absorbs carbonic acid from the atmosphere. It is precipitated, by the alkaline carbonates—in which it is insoluble, whether as an oxide, carbonate, or subsalt. It is distinguished from alumina, and glucina, by being insoluble in caustic potash: from yttria, by forming with sulphate of potash, a double salt, insoluble in a cold solution of sulphate of potash. It is distinguished from zirconia, by the latter being, after precipitation from a hot solution of sulphate of potash, almost insoluble in water, and the acids: and by being precipitated with ferrocyanide of potassium, which is not the case with zirconia.

663. TIN:—*symb.* Sn; * *equiv.* 58·82. It was known to the ancients. The Phœnicians were well acquainted with the tin of Cornwall. Before the method of working iron was discovered, an exceedingly hard compound of copper and tin was used for cutting instruments:—but its utility was greatly diminished, by its being incapable of receiving a *temper* [533], like steel. Swords, &c., of this material, are frequently found in Ireland, and other countries. Tin is obtained, from the native peroxide, by heating it with charcoal; and it is still further purified, by “liqutation”—that is, raising the metal to such a temperature, as causes the pure or “grain tin” to melt, the impurities being left in the residual mass, called “block tin.”

664. Tin is white, and brilliant. Its specific gravity is 7·291. Its surface soon becomes tarnished, by exposure to the atmosphere: yet it is very slowly oxidized by air, and moisture—and is, therefore, used to protect other metals. For this purpose, iron, and copper, are frequently coated with it—particularly the former, which then constitutes what is ordinarily termed “tin,” and is so commonly employed, for domestic purposes. It is very malleable; and may easily be reduced to leaves, the 2000th part of an inch in thickness.—Thin leaves of it, under the name of “tin-foil,” are used for electrical [elect. 47], and other purposes. Tin is soft and inelastic, and, when bent, emits a peculiar crackling noise: it is rendered more brittle, by fusion with bismuth. It melts at 442° , and its surface, if exposed to

* *Stannum*, tin. *Lat.*

the atmosphere, is then covered with a gray powder. Like lead, when heated to near its melting point, it is brittle. It burns with a colourless flame, at a white heat, peroxide being formed. Strong sulphuric acid, with the aid of heat, dissolves half its weight of tin. It is soluble, also in hot nitric acid: but almost all of it falls down again, as peroxide. Hydrochloric acid dissolves it, and then emits fumes. Added, by small quantities at a time, to aqua regia, it produces a solution, which is used, by dyers, to heighten the colours of cochineal, &c., so as to change them, from crimson to bright scarlet.

665. Tin forms, with oxygen, protoxide (SnO ; 66·82)—remarkable, from the tendency of its salts to absorb oxygen, which renders them powerfully deoxidizing agents: sesquioxide (Sn_2O_3 ; 141·64); and peroxide (SnO_2 ; 74·82). With chlorine, protochloride (SnCl ; 94·29), and perchloride (SnCl_2 ; 129·76). With iodine, protiodide (SnI ; 185·67), and biniodide (SnI_2 ; 312·52). With sulphur, protosulphuret (SnS ; 74·82); sesquisulphuret (Sn_2S_3 ; 165·64): and bisulphuret (SnS_2 ; 90·82), &c.

666. *Peroxide of tin* (SnO_2), is the most infusible of all the metallic oxides. It constitutes, when melted with glass [385], a white enamel. Acting as a feeble acid, it forms a class of salts called *stannates*. It exists, in two states:—when precipitated from persalts, by alkalies, it dissolves easily, in potash, and the acids: which is not the case, when it is obtained, by acting on tin with nitric acid. The soluble is changed into the insoluble peroxide, by ignition: and the insoluble, into the soluble, by fusion with carbonate of soda.

667. *Protochloride of tin* (SnCl), may be obtained, by melting pure tin, in an iron spoon: triturating the fused mass, and boiling an *excess* of it, along with concentrated hydrochloric acid, in a flask: then diluting the result with four or five times its bulk of water, acidulated with hydrochloric acid, and filtering. It is to be kept in a well-closed bottle, containing pieces of metallic tin:—without this precaution, it would be changed into perchloride.

668. The protosalts of tin are decomposed, by heat. Water added to solutions of neutral protosalts, causes milkiness—an insoluble basic salt being formed: hydrochloric acid renders the solution again clear. Potash, and ammonia—as also their carbonates—throw down from solutions of the protosalts, a white bulky hydrated protoxide ($\text{SnO} + \text{HO}$), that dissolves in potash. If the potash solution is heated, the protoxide is changed into peroxide, which remains dissolved, and metallic tin, which is precipitated as brown flakes. $2\text{SnO} = \text{SnO}_2 + \text{Sn}$. Sulphuretted hydrogen produces, in neutral, and acid solutions, and hydrosulphuret of ammonia, in all, a dark brown protosulphuret, soluble in potash, and in the alkaline hydrosulphurets—

particularly in those which contain excess of sulphur. The solution of this precipitate, in sulphuretted hydrosulphuret [253] of ammonia, affords, with acids, yellow bisulphuret of tin, along with sulphur. If it is boiled with nitric acid, it is changed into insoluble peroxide. Perchloride of mercury in excess, throws down, from solutions of the protochloride, or protoxide of tin, a white precipitate:—the latter is protochloride of mercury, the tin having taken half its chlorine from that metal. Perchloride of gold throws down, from the same solutions, if nitric acid is added, a purple precipitate—the “purple of Cassius,” which is insoluble in hydrochloric acid, and is, probably, a mixture of peroxide of tin, and metallic gold. Ferrocyanide and ferridcyanide of potassium throw down white precipitates. The salts of the protoxide, exposed to the atmosphere, are changed to those of the peroxide.

669. The persalts of tin are decomposed, at a red heat. Potash, ammonia, and their carbonates, thrown down from solutions, contain the persalts, a white hydrated peroxide ($\text{SnO}_2 + \text{HO}$) slightly soluble in ammonia, but easily so, in potash. Sulphuretted hydrogen, and hydrosulphuret of ammonia, throw down from acid, and neutral, solutions, a yellow bisulphuret, which is soluble in potash, in alkaline sulphurets, and in boiling hydrochloric acid; and is changed into peroxide, by boiling with nitric acid. Metallic zinc throws down metallic tin, in grayish white metallic spangles, or as a spongy mass, from solutions of the perchloride, or of persalts—not containing free nitric acid. If the latter is present, the precipitate will consist of hydrated peroxide, or of that substance and metallic tin.

670. TITANIUM:—*ymb. Ti; equiv. 24.33*. It was discovered by Gregor, in 1791, and received its name from Klaproth. It has been found, as titanitic acid, in many minerals. It occurs in clay iron stone:—and, therefore, in the smelting of iron, it is present in the slags, crystallized in very hard and brilliant cubes. It is obtained, by igniting the titanate of iron with sulphur. The results are sulphurous acid, sulphuret of iron, and free titanitic acid—which remain behind, when the sulphuret of iron is dissolved by hydrochloric acid. The titanitic acid is mixed with lampblack, and chlorine is passed through the mixture, heated to redness:—carbon unites with the oxygen of the acid, and chloride of titanium is formed. The latter is a colourless, and very volatile liquid, which fumes in the air: and combines with water so violently, as to cause explosion. This perchloride, by absorbing perfectly dry ammonia, forms a white substance ($\text{TiCl}_4 + \text{NH}_3$) which, if heated to redness, gives sal-ammoniac, nitrogen, and metallic titanium—the chlorine being removed by the hydrogen of the ammonia.

* From the *Titans* of heathen mythology.

671. Titanium, thus obtained, is in the form of a deep blue powder, which is liable to take fire, if exposed to the atmosphere while warm. In the solid form, it is of a bright copper colour. Its specific gravity is 5.3. It is nearly infusible. It is not acted on, by the air: but is oxidized, slowly, by melted nitre. It is dissolved, only by a mixture of nitric and hydrofluoric acids.

672. Titanium forms, with oxygen, oxide of titanium (TiO_2 ; 32.33); and titanous acid (TiO_2 ; 40.33). With chlorine, a volatile bichloride (TiCl_2 ; 95.27). With sulphur, bisulphuret (TiS_2 ; 56.33), &c.

673. Titanium is known, by giving, with ammonia, a white gelatinous hydrate, soluble in acids—and, to a certain extent, in alkaline carbonates. With ferrocyanide of potassium, a red brown precipitate. Titanous acid is precipitated, as a white powder, by sulphite of ammonia—with the aid of heat. Its solution in hydrochloric acid affords, with tincture of galls, an orange precipitate. The solution of an alkaline titanate in hydrochloric acid gives, with a bar of metallic zinc, or iron, a blue or violet oxide, which gradually alters to white:—the nascent hydrogen changes the acid to oxide, by combining with an atom of its oxygen. Tantalic [487] is distinguished from titanous acid, by the solubility of its hydrate, in caustic potash; and being thrown down, from its solution in hydrochloric acid, by sulphuric acid.

674. TUNGSTEN: *—*symb.* W; † *equiv.* 94.8. It was discovered by D'Elhuyar, in 1781: and is obtained, by boiling native tungstate of lime with hydrochloric acid—which dissolves out the lime, and leaves the tungstic acid, as a yellow powder. The latter, at a full red heat, is reduced by hydrogen.

675. Tungsten is of a grayish white colour. Its specific gravity is 17.5. It is very hard, brittle, and infusible:—it melts, however, before the oxy-hydrogen blow-pipe. It is very insoluble in acids—which is the case, also with its oxide. Acted upon, by nitre, it becomes tungstic acid:—the latter is produced, likewise, when the metal is heated to redness, in atmospheric air. Digested with a strong solution of caustic potash, it forms tungstate of potash, hydrogen being disengaged.

676. Tungsten forms, with oxygen, deutoxide (WO_2 ; 110.8): blue oxide (W_2O_3 ; 213.6); and tungstic acid (WO_3 ; 118.8). It forms with chlorine, bichloride (WCl_2 ; 165.74), and perchloride (WCl_6 ; 201.21). With sulphur, bisulphuret (WS_2 ; 126.8); and persulphuret (WS_6 ; 142.8), &c.

677. If deutoxide of tungsten is combined with soda, a substance ($2\text{WO}_2 + \text{NaO}$) is produced which greatly resembles

* *Tung sten*, heavy stone, *Swed.*; on account of the density of its ores.

† From *Wolfram*, a mineral, in which it is found.

gold. It may be obtained, by adding to fused tungstate of soda, as much tungstic acid as it can dissolve, exposing the result, at a full red heat, to a current of hydrogen, and then dissolving out the tungstate of soda. The residue will consist of brilliant scales, and cubes, which are like gold in colour: are insoluble in alkalis, or in acids—including even aqua regia, that [358] dissolves gold itself: and are acted upon, only by strong hydrofluoric acid.

678. When zinc is immersed in acid solutions of tungstic acid, it produces a beautiful blue colour—on account of the formation of tungstic oxide. If a tungstate is decomposed by an acid, in the presence of hydrosulphuret of ammonia, a blackish brown sulphuret of tungsten (WS_2) is precipitated.

679. URANIUM: *—*symb.* U: *equiv.* 60. It was discovered by Klaproth, in 1789: and may be obtained from *pitchblende*—a Saxon mineral, consisting of protoxide of uranium and oxide of iron, mixed with the sulphurets of lead and copper—by heating it to redness: reducing it to a fine powder: and digesting it in a smaller quantity of nitric acid, mixed with three or four parts water, then will dissolve the whole of the mineral. This changes the protoxide of uranium into peroxide, which combines with the nitric acid, to the almost total exclusion of the iron. The lead, and copper, present in the solution, are then thrown down, by sulphuretted hydrogen: and the excess of the latter is expelled by boiling. After this, the solution is concentrated by evaporation, and left to crystallize.—The nitrate separates, in the form of flattened, four-sided prisms, of a beautiful lemon colour; which, being heated to redness, are changed to yellow oxide: and are converted, by a strong heat, into sesquioxide. The latter is reduced to protoxide—long considered as the metal itself—by mixing it with charcoal, and passing chlorine over the mixture, strongly ignited. This forms protochloride, which, being acted on with potassium, gives metallic uranium.

680. Uranium resembles silver: and is malleable. It is very combustible: and, when in contact with acids, decomposes water—hydrogen being evolved.

681. Uranium forms, with oxygen, protoxide (UO ; 68) which, with a double atomic weight (U_2O_2), has, under the name of *uranyle*,† been considered as the radical of the ordinary salts of uranium. It forms also, sesquioxide (U_2O_3 ; 144); uranoso-uranic oxide ($UO + U_2O_3$; 212); and peroxide of uranium (U_2O_6 ; 160) which, it is probable, should be termed uranic acid—since, though it changes paper, stained red with

* From the planet Uranus, discovered in the same year.

† The termination *yle* is derived from *ulā*, the material of which any thing is made. *Gr.*—We shall find it employed very frequently, hereafter.

an infusion of logwood, to blue, it reddens moistened turnsole paper. This oxide is used to give glass a lemon colour. Uranium combines also with chlorine, &c.

682. Uranium in solution, is thrown down by the caustic alkalies, as a greenish hydrated sesquioxide: which, by absorbing oxygen, and becoming peroxide, rapidly changes to yellow. The hydrated sesquioxide dissolves in acids, forming yellow solutions: heated to about 300° , it becomes anhydrous, and of a bright brick colour:—at a higher temperature, it becomes uranoso-uranic oxide, of a deep gray colour. Heated on platinum wire with microcosmic salt, in the oxidating flame of the blow-pipe, it melts into a clear yellow glass, which, on cooling becomes green. Uranium gives with ferrocyanide of potassium a red brown: and with ferridcyanide a brown precipitate.

683. VANADIUM:—*ymb.* V; *equiv.* 68.66. It was discovered by Sefström, in 1830: and may be obtained, from a mineral, which is found at Wanlockhead, in Scotland—and consists, chiefly, of vanadate of lead—by dissolving it in nitric acid: precipitating the lead, and any arsenic present, by sulphuretted hydrogen—which deoxidizes the vanadic acid: and evaporating the blue solution to dryness—which reproduces the acid. The residue is then dissolved in ammonia: and the resulting vanadate of ammonia—which is insoluble in a strong solution of sal-ammoniac—is precipitated, by adding to the solution containing it, a larger piece of sal-ammoniac than it can dissolve. This separates the vanadic from arsenic acid, if any remains: and, also, from phosphoric and hydrochloric acid. The precipitated vanadate is washed, first in a solution of sal-ammoniac, and then in alcohol, specific gravity 0.86: and is afterwards heated to below redness, in an open platinum crucible, the mass being kept well stirred, until it acquires a dark red colour. The resulting vanadic acid, is changed, by means of charcoal, or hydrogen, and the application of heat, into the protoxide, which is a fine black powder, when it is broken down. This powder is mixed with charcoal, and a current of dry chlorine is transmitted through the mixture, heated to low redness. Terchloride passes over, in vapour, and is condensed into a yellow liquid, from which the free chlorine may be removed by a current of dry air:—water, or moist air would convert it into hydrochloric, and vanadic acid. The terchloride being introduced into a bulb, which has been blown in a barometer tube, dry ammoniacal gas is passed into it, and is rapidly absorbed—a white saline mass being produced. When this is heated, the sal-ammoniac is expelled, and the residue is vanadium.

684. Vanadium, thus obtained, has a strong metallic lustre,

* From *Vanadis*, a Scandinavian deity.

and resembles molybdenum, in appearance :—on attempting to remove it from the bulb, it falls into powder. It is not oxidated by water : but acquires a reddish tint, by exposure to the air. It is soluble, in nitric acid, and aqua regia—the solution being of a dark blue colour. It is not dissolved by sulphuric, hydrochloric, or hydrofluoric acid—whatever may be the temperature : nor is it oxidized by boiling with caustic potash, nor by the alkaline carbonates, at a red heat.

685. Vanadium forms, with oxygen, protoxide (VO ; 76.66) ; deutoxide (VO_2 ; 84.66) ; and vanadic acid (VO_3 ; 92.66). With chlorine, bichloride (VCl_2 ; 139.60) ; and terchloride (VCl_3 ; 175.07). With bromine, bibromide (VBr_2 ; 228.60). With sulphur, bisulphuret (VS_2 ; 100.66) ; and tersulphuret (VS_3 ; 116.66), &c.

686. Oxide of vanadium is thrown down from its solution, by potash, as a white hydrate, soluble in excess. By hydrosulphuret of ammonia, as a brownish black precipitate, soluble in excess, the solution being purple.

687. Vanadic acid, in solution, gives, with hydrosulphuret of ammonia, a brown tersulphuret, soluble in excess—the solution being brown. With ferrocyanide of potassium, a green precipitate. With chloride of barium, a bulky orange yellow precipitate, not quite insoluble in water. With sal-ammoniac, a white flocculent vanadate of ammonia, which is insoluble in hydrochloric acid.

Oxides of vanadium give, with borax, or microcosmic salt, in the outer flame of the blow-pipe, a yellow, in the inner flame, a green bead. Vanadic acid gives, with borax, or microcosmic salt, a brown glass—which becomes green, on cooling.

688. YTTRIUM :*— *symb. Y ; equiv. 32.25.* It was discovered by Wöhler, in 1828 : and is found in the Bohemian garnet, also in some rare Swedish minerals. It is obtained, by precipitating yttria, from its solution, with caustic potash ; and heating the last portion of the precipitate [499 and 659], along with potassium.

689. Yttrium is of a grayish black colour : of a scaly texture : and brittle. It is not acted upon by air, or moisture ; but it burns splendidly in air—and still more so in oxygen. It is soluble in sulphuric acid, &c. : and partially so, in caustic potash.

690. Yttrium forms, with oxygen, oxide (YO ; 40.25)—the earth yttria. It combines, also with sulphur, selenium, &c.

691. Yttria is thrown down, by potash, as a white precipitate. It is precipitated, also, by the alkaline carbonates, the resulting carbonate being soluble in excess, and dissolving easily in carbonate of ammonia :—crystals of the double carbonate of ammonia and yttria may be obtained from the solution.

* Because obtained from an earthy substance, found at Ytterby, in Sweden.

Phosphate of soda gives a white precipitate, which is soluble in hydrochloric acid, but is reprecipitated, by boiling. Ferrocyanide of potassium, gives a white precipitate.

692. ZINC :*—*symb.* Zn ; *equiv.* 32·53. It was first mentioned by Paracelsus, in the sixteenth century ; but was probably known long before. It is found abundantly in nature, as “zinc blende,” a sulphuret : and as “calamine,” a carbonate, or silicate. It is obtained from the native carbonate, by heating with carbonaceous matter :—the carbonic acid is driven off, and the oxygen of the residual oxide combines with the carbon. Zinc is obtained by methods, very similar to those which are used, in procuring lead from its ores : but the zinc is volatilized by the high temperature, and is received in water. That of commerce generally contains carbon, iron, &c. :—it may, however, be purified by redistillation, the first part of the product, containing the cadmium and arsenic, being rejected.

693. Zinc is a brilliant, bluish white metal, of a crystalline texture. Its specific gravity is 7·0. It is hard : and, near the point of fusion, is very brittle. Between 210° and 300° it is malleable, and ductile. It melts at 773° : and is volatilized, at a full red heat. Fused, in open vessels, it is oxidated—forming “flowers of zinc.” If it is heated to redness, in a covered crucible, and the cover is suddenly removed, it burns with a brilliant white light :—the product is an exceedingly light substance, which has been termed “philosophical wool,” and “white nothing.” Exposed to air and moisture, it is soon covered with a gray coating of suboxide, which greatly protects it from further action. When pure [gal. 16], it is not acted upon by sulphuric acid, except in contact with another metal. It dissolves rapidly in nitric, and in hydrochloric acid, &c.

694. Zinc forms, with oxygen, oxide (ZnO ; 40·53), which is lemon coloured while hot. With chlorine, chloride ($ZnCl$; 68). With iodine, iodide (ZnI ; 159·38). With bromine, bromide ($ZnBr$; 112·5). With sulphur, sulphuret (ZnS ; 48·53), &c.

I have already mentioned [492] some very important compounds of zinc with other metals, which are extensively used in the arts.

695. *Chloride of Zinc* ($ZnCl$) may be obtained, by dissolving zinc in hydrochloric acid.

696. Zinc is precipitated from its solutions, by potash, or ammonia, as a white hydrate ($ZnO + HO$), soluble in excess. The alkaline carbonates throw down a white basic carbonate [$2(CO_2 + ZnO) + 3(ZnO + HO)$], soluble in potash, ammonia, and carbonate of ammonia. Ammoniacal salts prevent the formation of this precipitate : or, being afterwards added, dissolve it—

* *Zinken*, nails. *Ger.* :—from its frequently assuming a form, somewhat resembling nails.

forming double salts of zinc and ammonia. Sulphuretted hydrogen throws down, from neutral solutions, and hydrosulphuret of ammonia, from all that are not very acid, a white sulphuret (ZnS), soluble in hydrochloric, nitric, or dilute sulphuric acid. Ferrocyanide of potassium, causes a white gelatinous precipitate, insoluble in hydrochloric acid. Ferridcyanide of potassium, a yellowish red precipitate, soluble in hydrochloric acid.

If oxide of zinc, either free, or in combination, is moistened with a solution of protonitrate of cobalt, and is then heated with the blow-pipe, an unfused mass—consisting of oxide of zinc and protoxide of cobalt—of a fine green colour, will be obtained.

697. ZIRCONIUM : *—*symb.* Zr ; *equiv.* 33·67. It was procured by Berzelius, in 1824, from the zircono-fluoride of potassium (the double fluoride of zirconium and potash), in the same way as silicon is obtained [373] from the silico-fluoride of potassium.

698. Zirconium is a black powder which, even when pressed, has only a doubtful metallic lustre: and has not, as yet, been found, in any circumstances, to conduct electricity. It takes fire, in the atmosphere, at a temperature below incandescence. Boiling in water does not alter it. It dissolves, with facility, in hydrofluoric acid:—and no other acid has much effect upon it.

Zirconium forms, with oxygen, oxide (Zr_2O_3 ; 91·34) or “zirconia.” It combines, also, with sulphur, &c.

699. Zirconia is thrown down, by potash, and ammonia, as a white precipitate:—the ammonia sometimes gives a subsalt, instead of the sesquioxide. Alkaline carbonates throw down a carbonate, slightly soluble in excess. Ferrocyanide of potassium, causes a white precipitate. When its solution is neutralized with potash, zirconia, like thorina [662], forms, with sulphate of potash, a white double salt, insoluble in a saturated solution of the sulphate. But, it is distinguished from thorina, by emitting a glaring white light, during ignition:—zirconia, also, is much heavier than thorina.

700. COMPORTMENT OF THE METALS, WITH RE-AGENTS.—The following is a synopsis of the characters, by which the various metals may be distinguished from each other: and will probably be found to save considerable trouble.—Those which give precipitates that are soluble in excess [47], are marked with a star. And when the precipitate has any peculiar characteristic, reference is made to the paragraph in which it is described—

* So called, from one of the names, by which the *jargon*, a stone of Ceylon, resembling the diamond, is known.

Acetate of lead gives, with—

Chromium, as chromic acid, a

Colours of
precipitates.
Yellow.

Ammonia gives, with—

Aluminum* [434]

Antimony, as protosalt,

Bismuth

Cadmium*

Cerium [471]

Copper,* as subsalt [496],

Glucinum

Iron, as protosalt, ammoniacal salts not being
present [537],

Lanthanum

Lead,* not as acetate,

Magnesium—unless the solution is acid, or an am-
moniacal salt is present [558],

Manganese, as protosalt—sal-ammoniac not being
present [563],

Mercury, as persalt,

Tellurium, as tellurous acid,

Thorium

Tin, as protosalt

Titanium

Zinc*

Zirconium [699]

White.

Gold, in tolerably concentrated solutions [509],
Platinum,* if the solution is not too dilute, and free
hydrochloric acid is present,

Yellow.

Rhodium, as sesquioxide—after some time,

Cobalt,* much sal-ammoniac not being present
[482],

Blue.

Copper,* as black oxide—sometimes [497],

Chromium,* as sesquioxide [476],

Copper,* as black oxide—sometimes [497],

Nickel,* unless an ammoniacal salt or free acid is
present [586],

Green.

Uranium [682]

Iron, as peroxide

Silver*—ammoniacal salts should not be present,

Brown.

Mercury, as subsalt,

Molybdenum, as molybdous oxide,

Ruthenium, as aqueous solution of chloride [634],

Black.

Ammonio-nitrate of silver gives, with—

Arsenic,* in acid solutions, a

Yellow.

Ammonio-sulphate of copper gives, with—

Arsenic, in acid solutions, a

Green.

Antimoniate of potash gives, with—

Sodium, in neutral or alkaline solutions, which
are not too dilute:—potash should not be pre-
sent, as carbonate [652], a

White.

Bichloride of platinum gives, with—

Potash—any ammonia present having been removed [623], a little hydrochloric acid being poured in before the re-agent, the liquid being evaporated to dryness at 212°, and finally the residue being treated with a little cold water—a

Colours of
precipitates.

Yellow.

Carbonate of Ammonia gives, with—

Aluminum
Antimony, as protosalt,
Bismuth
Glucinum
Lanthanum
Lead
Manganese, as protosalt,
Silver*
Strontium—the solution should not be acid [655],
Tellurium,* as tellurous acid,
Thorium
Tin
Yttrium*
Zinc*
Zirconium*

White.

Rhodium, as sesquioxide, after some time, a

Yellow.

Copper,* as black oxide—sometimes a

Blue.

Copper,* as black oxide—sometimes

Green.

Nickel*

Cobalt [482], a

Red.

Molybdenum,* as molybdous oxide, a

Black.

Carbonate of potash gives, with—

Aluminum
Antimony, as protosalt,
Bismuth [456]
Cadmium, ammoniacal salts should not be present,
Glucinum*
Lanthanum
Lead
Magnesium, in neutral solutions, ammoniacal salts
not being present, and the liquid being boiled [558],
Manganese, as protosalt,
Silver
Strontium—the solution should not be acid,
Tellurium,* as tellurous acid [658],
Thorium
Tin
Yttrium*
Zinc—ammoniacal salts should not be present,
Zirconium*

White.

Nickel, a

Green.

Cobalt [482], a

Red.

Mercury, as persalt—ammoniacal salts not being
present [574], a

Brown.

Molybdenum,* as molybdous oxide, a

Black.

<i>Carbonate of soda gives, with—</i>					Colours of precipitates.
Aluminum	} <i>White.</i>
Antimony, as protosalt,	.	.	.	.
Barium	.	.	.	.
Bismuth [456]	.	.	.	.
Cadmium—ammoniacal salts should not be present,	.	.	.	.
Glucinum*	.	.	.	.
Lanthanum	.	.	.	.
Lead	.	.	.	.
Manganese, as protosalt,	.	.	.	.
Silver	.	.	.	.
Strontium—the solution should not be acid,	.	.	.	.
Tellurium,* as tellurous acid,	.	.	.	.
Thorium	.	.	.	.
Yttrium*	.	.	.	.
Zinc—ammoniacal salts should not be present,	.	.	.	.
Zirconium*	} <i>Green.</i>
Nickel, a	.	.	.	.
Cobalt [482], a	.	.	.	.
Mercury, as persalt, ammoniacal salts not being present [574], a					} <i>Brown.</i>
<i>Chloride of barium gives, with—</i>					
Chromium, as chromic acid,	} <i>White.</i>
Molybdenum, as molybdic acid,	.	.	.	.
Vanadium, as vanadic acid [687], a	<i>Yellow.</i>
<i>Chloride of calcium gives, with—</i>					
Arsenic, as arsenious acid, a	<i>White.</i>
<i>Chloride of potassium gives, with—</i>					
Platinum,* in a solution not too dilute, and free hydrochloric acid being present, a	} <i>Yellow.</i>
<i>Chloride of sodium gives, with—</i>					
Lead	} <i>White.</i>
Mercury, as subsalt,	.	.	.	.
Silver	.	.	.	.
<i>Chromate of potash gives, with—</i>					
Bismuth	} <i>Yellow.</i>
Lead	.	.	.	.
Strontium, the liquid being boiled,	} <i>Red.</i>
Mercury, as subsalt, a	.	.	.	.
Copper, as black oxide,	} <i>Brown.</i>
Silver,	.	.	.	.
<i>Cyanide of potassium gives, with—</i>					
Cobalt*	} <i>White.</i>
Palladium	.	.	.	.
Copper,* as black oxide, a	<i>Green.</i>
Nickel,* a	<i>Yellow.</i>

		Colours of precipitates.
<i>Ferridcyanide of potassium</i> gives, with—		
Tin, as protosalt, a	.	White.
Bismuth .	.	Yellow.
Mercury, as persalt [574],	.	
Iron, as protoxide, a	.	Blue.
Copper, as black oxide, a	.	Green.
Cobalt .	.	Brown.
Manganese .	.	
Nickel .	.	
Silver .	.	
Zinc, a	.	Red.
<i>Ferrocyaniide of potassium</i> gives, with—		
Bismuth .	.	White.
Cerium .	.	
Columbinum, as tantalic acid,	.	
Iron, as protosalt [537],	.	
Lead .	.	
Mercury, as [573 and 574],	.	
Silver .	.	
Tin, as protosalt,	.	
Yttrium .	.	Yellow.
Zinc .	.	
Zirconium .	.	
Niobium, a	.	
Chromium, as chromic acid,	.	Green.
Cobalt [482]	.	
Nickel .	.	Brown.
Vanadium, as vanadic acid,	.	
Copper, as black oxide,	.	Pale red.
Titanium .	.	
Manganese [463]—free acids should not be present, a	.	
<i>Hydrochloric acid</i> gives, with—		
Lead .	.	White.
Mercury, as subsalt,	.	
Silver [642],	.	
<i>Hydrofluosilicic acid</i> gives, with—		
Barium, a	.	White.
<i>Hydrosulphuret of ammonia</i> gives, with—		
Aluminum .	.	White.
Columbium .	.	
Mercury, as persalt, when agitated,†	.	
Zinc, unless the solution is very acid,	.	
Antimony,* as protosalt,	.	Yellow.
Arsenic, the solution being acidified with hydrochloric acid [442],	.	
Cadmium .	.	
Tin,* as persalt, from neutral and acid solutions,	.	Flesh red.
Manganese, as protosalt, in alkaline solutions, [563], a	.	

with—

† The colour depends on the quantity of re-agent [574].

	Colours of precipitates.
Gold,* in neutral and acid solutions, . . .	Brown.
Molybdenum,* as molybdous oxide, . . .	
Platinum,* in acid, and neutral solutions [602], . . .	
Rhodium, as sesquisalt—after some time, . . .	
Tin,* as protosalt [668], . . .	
Vanadium,* as vanadic acid, . . .	Black.
Bismuth, in neutral and acid solutions. If excess of nitric or hydrochloric acid is present, water must be added, . . .	
Cobalt, in neutral solutions [482], . . .	
Copper* . . .	
Iron—if as persalt, in neutral solutions [538], . . .	
Lead . . .	
Mercury—if as persalt, enough of the re-agent being added [574], . . .	
Nickel, in neutral solutions [586], . . .	
Osmium . . .	
Palladium* . . .	
Silver . . .	
Vanadium,* as oxide, . . .	
<i>Iodide of potassium gives, with—</i>	
Mercury,* as subsalt, . . .	Yellow.
Silver . . .	
Mercury,* as persalt, a . . .	Red.
Palladium . . .	Black.
Platinum,* as chloride, . . .	
<i>Iron, in the metallic state, gives, with—</i>	
Titanium, as an alkaline titanate, a . . .	White.†
Copper, is precipitated from its salts, in the metallic state, by iron.	
<i>Nitrate of silver gives, with—</i>	
Molybdenum, as molybdic acid [581], a . . .	White.
Arsenic,* in neutral solutions,—just enough of the re-agent should be added [442], . . .	Yellow.
Chromium, as chromic acid, a . . .	Red.
<i>Oxalate of ammonia gives, with—</i>	
Calcium—free hydrochloric acid should not be present [468], . . .	White.
Cerium . . .	
Strontium . . .	
<i>Oxalic acid gives, with—</i>	
Calcium,* free hydrochloric acid should not be present [468], . . .	White.
Strontium [655],—particularly in presence of ammonia, . . .	
Gold, as terchloride, [509] a . . .	Metallic.

† It is first blue or violet, but gradually changes.

Colours of
precipitates.
Purple.

Perchloride of gold gives, with—

Tin, as protosalt, if nitric acid is added, a .

Perchloride of mercury gives, with—

Tin, as protosalt, the re-agent being in excess, a .

White.

Phosphate of soda gives, with—

Antimony, as protosalt,

Glucinum

Magnesium, in presence of ammonia [558], and the
other alkaline earths having been precipitated,

Manganese

Mercury, as subsalt,

Yttrium

Cobalt, a

White.

Blue.

Potash gives, with—

Aluminum*

Antimony,* as protosalt,

Bismuth

Cadmium

Cerium [471]

Glucinum*

Iron, as protosalt—ammoniacal salts should not
be present [537],

Lanthanum

Lead*

Magnesium

Manganese—sal-ammoniac should not be present
[563],

Tellurium,* as tellurous acid,

Thorium

Tin*

Vanadium,* as oxide,

Yttrium

Zinc*

Zirconium

White.

Mercury, as persalt. Enough potash must be
added [574],

Platinum,* in a solution not too dilute, and free
hydrochloric acid being present [602],

Rhodium, as sesquisalt—after protracted digestion,

Cobalt, much sal-ammoniac not being present [482],

Copper, as black oxide [497],

Chromium,* as sesquioxide [476],

Nickel

Uranium [682]

Gold, as terchloride, and not a cold acid solution
—after some time,

Palladium*

Silver—ammoniacal salts should not be present,

Mercury, as subsalt,

Molybdenum, as molybdous oxide,

Yellow.

Blue.

Green.

Brown.

Black.

		Colours of precipitates.
<i>Protochloride of tin</i> gives, with—		
Mercury, a	.	Gray.
Gold, in concentrated solutions—a drop of nitric acid being added, a	.	} Purple red.
Platinum, unless the quantity is too small [602], a	.	
Silver [642], a	.	Brown.
	.	Metallic.
<i>Protonitrate of mercury</i> gives, with—		
Chromium, as chromic acid, an	.	Orange.
Gold, as terchloride, a	.	Black.
<i>Protosulphate of iron</i> gives, with—		
Gold, as auric acid [509], a	.	Brown.
Silver, a	.	Metallic.
<i>Sal-ammoniac</i> gives, with—		
Vanadium, as vanadic acid, a	.	White.
Platinum,* in a solution not too dilute, and free hydrochloric acid being present [602], a	.	} Yellow.
Molybdenum, as molybdic oxide, a	.	
	.	Brown.
<i>Soda</i> gives, with—		
Aluminum*	.	} White.
Bismuth	.	
Lanthanum	.	
Tellurium, as tellurous acid,	.	
Thorium	.	
Uranium [682], a	.	Greenish.
<i>Sulphate of copper</i> gives, with—		
Arsenic, in neutral solutions, a	.	Green.
or a	.	Greenish blue.
<i>Sulphate of potash</i> gives, with—		
Barytes	.	} White.
Calcium, in concentrated solutions [468],†	.	
Lead	.	
Strontium, in concentrated solutions,	.	
Thorium, the re-agent being in excess, and the fluid concentrated [662], then cooled,	.	
Zirconium—enough of the re-agent must be present [699],	.	
	.	
<i>Sulphite of ammonia</i> gives, with—		
Tellurium, as tellurous acid [658], a	.	Black.
Titanium, as titanlic acid, heat being applied, a	.	White.
Silver, a	.	Metallic.
<i>Sulphocyanide of potassium</i> gives, with—		
Columbium, as tantalic acid, a	.	White.
Niobium, a	.	Yellow.
Iron, as persalt, a blood red tint.	.	

† Slowly, or not at all, in very dilute solutions [468].

		Colours of precipitates.
<i>Sulphuret of potassium</i> gives, with—		
Cerium, a		<i>White.</i>
<i>Sulphuretted hydrogen</i> gives, with—		
Mercury as persalt, the solution being agitated,† .	}	<i>White.</i>
Zinc, in neutral solutions,		
Antimony,* as protosalt, in an acid solution, .	}	<i>Yellow.</i>
Arsenic, the solution being acidified with hydrochloric acid,		
Cadmium—if free acid is present, water must be added,		
Chromium, as chromic acid, free acid being present,‡		
Iron, as persalt,‡	}	<i>Flesh red.</i>
Tin, as persalt, in neutral, and acid solutions, . .		
Manganese, in acid solutions [563], a	}	<i>Brown.</i>
Gold, in neutral, and acid solutions,		
Iridium		
Molybdenum, as molybdic acid, the re-agent being in excess—after a while,		
Platinum, in neutral, and acid solutions,	}	<i>Black.</i>
Rhodium, as sesquisalt—after some time,		
Tellurium	}	<i>Black.</i>
Tin, as protosalt, in neutral, and acid solutions, .		
Bismuth, in neutral, and acid solutions. If excess of nitric or hydrochloric acid is present, water must be added.	}	<i>Black.</i>
Copper, as black oxide,		
Iron, as protoxide, in alkaline solutions,	}	<i>Black.</i>
Lead—if much mineral acid is present, water must be added		
Mercury, as subsalt—if as persalt, the re-agent must be in sufficient quantity [574],	}	<i>Black.</i>
Nickel, in alkaline solutions [586],		
Osmium	}	<i>Black.</i>
Palladium		
Silver	}	<i>Black.</i>
<i>Sulphuric acid</i> gives, with—		
Barium	}	<i>White.</i>
Calcium—the solution should not be too dilute [468], .		
Columbium, as tantalic dissolved in hydrochloric acid,	}	<i>White.</i>
Lead		
Strontium, in solutions not too dilute [655],	}	<i>White.</i>
<i>Sulphurous acid</i> gives, with—		
Osmium, a <i>yellow</i> , &c. [593], solution.	}	<i>Black.</i>
Tellurium, as tellurous acid [658], a		

† The colour depends on the quantity of re-agent [574].

‡ The precipitates with chromium, and iron, are sulphur.

		Colours of precipitates.
<i>Tartaric acid</i> gives, with—		
Potassium, in neutral or alkaline, and not too dilute solutions [623]—the re-agent being in excess, .	}	<i>White.</i>
Sodium, in highly-concentrated solutions [652], .		
<i>Tin</i> , in the metallic state, gives, with—		
Molybdenum, as molybdic acid—free hydrochloric acid being present—a <i>blue</i> , then a <i>green</i> , and lastly a <i>black</i> tint.		
<i>Tincture of galls</i> gives, with—		
Columbium, as tantalic dissolved in hydrochloric acid, a	}	<i>Yellow.</i>
Iron, as peroxide—sometimes a		<i>Violet.</i>
Osmium, a <i>purple</i> tint &c. [593],		
Titanium, as titanitic dissolved in hydrochloric acid, an	}	<i>Orange.</i>
Iron, as peroxide—sometimes a		<i>Black.</i>
<i>Water</i> gives, with—		
Antimony, as protochloride—tartaric acid not being present [437],	}	<i>White.</i>
Bismuth, as chloride,		
Tin, as neutral protosalt, a <i>milky</i> ness.		
<i>Zinc</i> , in the metallic state, gives, with—		
Columbium, as tantalic acid—hydrochloric acid being added in excess,	}	<i>White.</i>
Silver		
Titanium, as an alkaline titanate, dissolved in hydrochloric acid, †	}	<i>Gray.</i>
Cadmium		
Tin, as persalt—free nitric acid not being present,	}	
Molybdenum, as molybdic acid—free hydrochloric acid being present—a <i>blue</i> , then <i>green</i> , and lastly <i>black</i> tint.		
Tungsten, as tungstic acid, a <i>blue</i> tint.		
Niobium, as niobic acid—free hydrochloric acid being present [589],	}	<i>Brown.</i>
Antimony [438]		
Platinum [602]	}	<i>Black.</i>
Ruthenium, as chloride [634], acidified with hydrochloric acid,		
Tellurium, as tellurous acid [658],	}	
Copper is precipitated on the surface of zinc, immersed in a fluid containing it.		

† The precipitate is first blue, or violet.

CHAPTER VI.

ORGANIC CHEMISTRY.

Structure of Plants, 1.—The Roots, 6.—The Stem, 13.—Buds, 15.—Leaves, 16.—Digestion, and Respiration of Plants, 20.—The Flower, 26.—The Fruit, 27.—The Seed, 29.—Peculiarities of Organic Elements, and their Compounds, 31.—Oxalic Acid, 42.—Cyanogen, 48.—Hydrocyanic Acid, 53.—Uric Acid, 62.—Acetic Acid, 69.—Formic Acid, 78.—Tartaric Acid, 82.—Racemic Acid, 89.—Citric Acid, 90.—Malic Acid, 94.—Tannic Acid, 98.—Manufacture of Leather, 102.—Gallic Acid, 104.

1.—STRUCTURE OF PLANTS.—Since most of the substances, of which I shall treat hereafter, are those elements of plants which—from being ready formed in, or produced by them—are termed *proximate*, it is right that I should here explain the nature and general characters of vegetables. This is the more important, as one of the chief uses of chemical knowledge is its application to agriculture.

2. Organized are generally distinguished, without difficulty, from inorganized beings. Inorganic matter increases by external addition, atom being added to atom:—hence, the regular form of crystals, &c. Organized matter increases by interstitial deposition, and grows in all directions:—hence, its irregular forms. Inorganic matter is subject to the ordinary chemical laws: vitality causes these laws to be suspended. Inorganic bodies contain no principles of increase, repair of waste, or replacement; living beings suppose the processes of nutrition, and of reproduction. The difference between animals and plants is, also, generally very distinct.—The transformation of nutriment into the living substance or, as it is called, “assimilation,” is the character of mere organic, “in-nervation,” that of animal existence. Plants have not, like animals, the power of locomotion, sensation, or volition. They do not, like them, gradually renew their structure.—Animals change, not only the soft parts of their bodies, but even, in a few years, their very bones. Inorganic matter is the nutriment of plants: organic matter, that of animals. Nevertheless, it must be admitted that the mineral, the vegetable, and the animal kingdoms blend into each other so imperceptibly that, however we may attempt to separate, or to mark the boundaries between

them, it is scarcely possible to say where one terminates, and another begins.—But, our knowledge on this subject is much more clear, at present, than formerly.

3. Organized substances are constituted of but few elements.—Vegetables consist, principally, of carbon, hydrogen, and oxygen; animal substances, of carbon, hydrogen, oxygen, and nitrogen. Some vegetable substances, however, do, and some animal substances do not contain nitrogen. It is always present, in the fluids which pervade the organs of plants: and is, sometimes found in the roots—as, for instance, in those of *beet*; at others, in the stem—as in that of the *maple*;—it is detected in all blossoms, and unripe fruits. Some organic substances contain carbon and hydrogen, but no oxygen; in others, the oxygen is more, or less, than is sufficient, along with the hydrogen, to form water. Organic matter sometimes affords, also, sulphur, phosphorus, chlorine, fluorine, iron, lime, magnesia, potassium, sodium, &c., in small quantities.

4. The organs of plants are intended for respiration, nutrition, reproduction, or mechanical support. Plants are termed *phanerogamic*,* when they have pistils and stamina, the sexual organs: they are *cryptogamic*† when, like ferns, mosses, furze, &c., these organs are not perceptible.—The cryptogamic are more properly termed *agamic*,‡ since the pistils, and stamina, are not merely hidden, but altogether wanting. The agamic are called, also, *acotyledonous*§ plants, because, having no seed, they have not cotyledons.

5. All phanerogamic plants consist of a root, stem, branches, leaves, flowers, and seeds;—the cryptogamic want the last two. Every plant is covered with a cuticle,|| which, in some cases, imparts considerable strength:—that of several kinds of grass, &c., contains so much silex, in the form of a silicate of potash ($10\text{SiO}_3 + \text{KO}$), as to give fire with flint.

6. THE ROOTS.—Nutriment is absorbed only, by the extremities of the roots, called *spongioles*;¶ and, hence, the leaves are made to throw the rain, in the largest quantities, to those places, where these are situated. Trees are often injured, in *trenching*, from ignorance of the fact that the *extremities* of the roots are highly important, and extend to a considerable distance:—they gradually pass into fresh portions of earth, according as the parts from which nourishment was previously derived, are exhausted. The root never becomes green, even in the air.

* *Phaino*, I exhibit; and *gamos*, marriage. Gr.

† *Krupto*, I conceal; and *gamos*. Gr.

‡ *A*, a privative particle; and *gamos*. Gr.

§ *A*, a privative particle: and *cotyledon*, a lobe of the seed—literally, the hollow of a hip bone. Lat.

|| A diminutive of *cutis*, the skin. Lat.

¶ *Spongiolum*, a little sponge. Lat.

It is inserted in the soil, in water, or—if the plant is parasitic—in other plants: and is, generally, organized, like the stem.

7. The organic matter of the mould, consisting of decayed vegetables, &c., is perpetually forming carbonic acid. This is intended to be absorbed by the plant: and, until such absorption takes place, it protects the organic matter from further decomposition—which would be merely a source of waste. Water (or its elements) is assimilated, along with carbonic acid:—it serves, besides, as a vehicle for the food of plants. Charcoal and distilled—or rain—water will not, under ordinary circumstances, maintain plants in a thriving state: and they enable them, even to exist, only because of the salts contained in the charcoal, and of the ammonia which [inor. chem. 260] it condenses. It is probable that carbon does not constitute the food of plants, except when it is in the nascent state.

8. Dr. Priestly asserted, and it is now no longer doubtful, that nitrogen is absorbed by plants:—indeed their value, as articles of food, is chiefly dependent on the quantity of that element, which they contain. Some consider that the nitrogen is obtained directly from the atmosphere; others that it must previously assume the form of ammonia—by the nitrogen of the atmosphere uniting with nascent hydrogen, evolved by decomposing organic substances. Some plants have more power to assimilate nitrogen, than others.—Trefoil, planted in pure sand in which it thrives almost as well as in ordinary soil, has, when fully grown, twenty-six per cent. more nitrogen, than the seed which produced it. Wheat, in the same circumstances, does not come to maturity; and, in the end, contains less nitrogen, than was in the seed.

9. Plants have not the power of rejecting poisonous substances—sulphate of copper, for example, or the water that drains from a heap of manure, and which is injurious, because overcharged with nutriment.

10. When the plant has reached such maturity that the organs, by which it obtains food from the atmosphere, are formed, it no longer requires, from the mould, carbonic acid or moisture—provided the water (or its elements) necessary to be assimilated along with the carbonic acid, is supplied by dew.—Caoutchouc and wax often preserve, in plants that derive little or no nourishment from the soil, the moisture which they obtain from the atmosphere: as the skin, which forms on milk, protects it from evaporation.

11. Plants are ascertained to resemble animals, in having excretions:—these occur through the roots. Buchner found that the charcoal which had been used by Lukas—in experiments made, during several years, for the purpose of ascertaining its power of sustaining plants—contained a brown substance,

soluble in alkalis : this was *excrement*. The excretion of one species of plant, may be, not only not injurious, but even salutary to others.—Hence, one reason why rotation of crops is advantageous. Dr. Wollaston has shown that what are called “fairy rings,” and are formed by dark luxuriant grass, arise from fungi that commence at a point, and grow in successive circles. The place they occupied is incapable of producing them a second time, although grass will flourish there—and the more abundantly, on account of the decomposed roots, and excrement, of the preceding crop of fungi. Plants which, from the nature of their excrements, are fond of growing near each other, are said to be “social.” The acid excretions of plants contribute to the disintegration of rocks.

12. When the plant has produced leaves, it plentifully returns, in the shape of excrement, the nourishment which when young, it obtained from the earth, as carbonic acid : and this excrement, when decomposed, affords carbonic acid to the next generation of plants. Gigantic ferns, &c.—at first the only produce of the earth—were enabled, on account of the great size of their leaves, to dispense with nourishment from the ground : and, therefore, instead of exhausting, they fertilized it. Fallowing, or a succession of water containing oxygen, causes the decomposition of excrement.

13. THE STEM of plants is sometimes but little developed—as in the cowslip : such plants are termed *acaules*.* The stem of a forest tree—as that of the oak—is called a *trunk*. Such plants are termed *exogenous*,† because they increase by external rings, or concentric layers : the number of these, near the base, indicates the age. The “trunk” is peculiar to dicotyledonous plants. The stem of *endogenous*‡ plants, or those which increase internally, is called a *stipe*,§ and is peculiar to monocotyledonous plants.—I shall explain immediately, the difference between monocotyledonous, and dicotyledonous plants. The stipe increases, by rings, added longitudinally ; its age, therefore, is known by the number of its joints ; and its external diameter, when it is once consolidated, is never augmented. The *medullary canal* is in the middle of the trunk : and the pith is contained in the centre of its medullary tube :—the latter never alters, by age. The pith communicates with the *herbaceous integument*, by what are called the *medullary rays*.—Sometimes, the pith gradually disappears. The herbaceous integument is between the cuticle, and the *cortical*¶ layers, and is called the “outer pith”—which

* *A*, a private particle ; and *caulos*, a stem. *Gr.*

† *Ex*, out of ; and *gennao*, I produce. *Gr.*

‡ *Endon*, within ; and *gennao*, I produce. *Gr.*

§ *Stipes*, a stem. *Lat.*

¶ *Medulla*, marrow. *Lat.*

¶ *Cortex*, bark. *Lat.*

is well exemplified in the very familiar substance “cork.” It decomposes carbonic acid; and sap ascends through it, in spring, to the buds, carrying particles of nutriment ready formed. It is often difficult to distinguish the cortical layers from the *liber*,* so called, from containing what very much resembles the leaves of a book, and may generally be separated into laminæ—at least by maceration. Like all other parts of the bark, it is repaired, if removed, provided the air is excluded: but, if its upper and lower portions are quite severed, the tree will perish. The bark is, to the tree, what the wool is to the sheep—a preservative against cold.

14. The *alburnum*,† thus named, because it is, generally, of a white colour, consists of the woody layers, within the liber: it is termed also, the “false wood.” The *heart* wood is between the alburnum, and the medullary tube: and is formed, gradually, by the change of alburnum.—It is said, by some, to be a lifeless substance, intended only to impart strength; and it does not appear until when, after several years, this strength is required. In the stipe of monocotyledonous plants, the pith, wood, &c., are united, in a confused mass: or rather, we have reason to suppose—since additions are made to it, internally, as in the cortical system of the trunk belonging to dicotyledonous plants—that the central system is altogether wanting. In dicotyledonous plants, the *cambium*, or elaborated sap, is the means of increasing the stem, by forming a new layer of liber, and alburnum: in monocotyledonous, the terminal bud which crowns the stipe, performs the same function. Sometimes the stipe is cylindrical or even swelled out in the middle.

15. Buds are generally covered with scales: they contain the rudiments of stems, branches, leaves, and organs of fructification: and are always found upon branches, in the *axilla*‡ of leaves, or at the extremity of twigs: and are secured from the cold, externally, by a viscid resinous substance, but within, by a downy texture.—Vegetables in the torrid zone, or in a hothouse, have no such protection, for they do not require it. The bud appears, first, in summer, when vegetation is most vigorous: it grows, a little, in autumn: remains stationary, in winter; and expands, in spring. The buds of the greater part of herbaceous vegetables have no scales. *Bulbs* are a species of buds.

16. LEAVES consist of a bundle of vessels, proceeding from the stem, and forming a net-work filled up by *cellular substance*, which is a continuation of the herbaceous integument of the bark: and of *epidermis*,§ which is porous, having *stomata*,|| or openings, particularly on the under surface. When there is no

* *Liber*, a book. *Lat.*

† *Albus*, white. *Lat.*

‡ *Axilla*, the arm-pit. *Lat.*

§ *Epi*, upon; and *derma*, the skin. *Gr.*

|| *Stoma*, a mouth. *Gr.*

leaf-stalk, or *petiole*,* the leaf is *sessile*†—as in the poppy: otherwise, it is *petiolated*—as in the horse-chestnut. The petiole forms, by its continuation and branches, the projecting lines on the under part of the leaf, improperly called “nerves.” These sometimes terminate with *spines*‡—as in the holly: the *midrib* is that nerve, which is a direct continuation of the petiole. The down, on the under part of some leaves, favours the absorption of substances from the atmosphere.

17. Fluids are exhaled, principally from the upper surface:—in herbaceous plants, however, absorption is equal in both surfaces. When the soil is unfavourable, the absorption [10 and 12] is very great:—an analogous means has, sometimes, been applied to the nourishment of the human body. Exhalation, from the stomata, occurs, only when natural or artificial light is present. The leaves, though not primarily intended for that purpose, absorb water. Their fall seems to arise from the suspension of vegetation, and interruption of the course of the sap; or from the silex, which is deposited by the sap, and which, when once precipitated, is never again taken up.

18. Plants which have the largest leaves, are the least injurious to the ground:—they do not exhaust it so much as others, on account of deriving a large portion of their nourishment, from the atmosphere. Hence one reason why green crops are more beneficial than grain crops. Trees that annually shed their leaves, require a greater amount of alkali, in the soil, than pines, &c.

19. The sap ascends through the alburnum, and wood: and the more abundantly, the nearer to the medullary tube. When it reaches the leaves, it is freed from atmospheric air, &c., and gives off its superfluous water, by *transpiration*. Nearly two-thirds of the sap exhale through the stomata; and a sun-flower was found, by Hales, to lose by such evaporation, seventeen times more moisture, than an equal surface of the human body, by insensible perspiration. Sap has been known to rise, in a tube [hyd. 107], to a height equivalent to forty-three feet of water pressure. The roots and leaves of plants absorb various fluids; these are partially returned to the atmosphere, by what is called *expiration*.

20. DIGESTION, AND RESPIRATION OF PLANTS.—Light, acting on the leaves, and other green parts of the plant, decomposes the carbonic acid, which is obtained either from the sap or the atmosphere, oxygen being evolved. This process is called the *digestion* of plants. It occurs even with leaves separated from the plant: since, if they are placed in water containing carbonic acid, oxygen will be evolved by the action of

* *Petalon*, a leaf. Gr. † *Sedeo* I sit. Lat.

‡ *Spina*, a thorn. Lat.

the sun's light. From this decomposition of carbonic acid, by vegetables, it may be easily conceived, how vast a quantity of oxygen is set free, in the hotter portions of the earth. The air, therefore, which passes from the tropics [pneum. 104] towards the polar regions, is not only a means of moderating the cold, but also, being extremely rich in oxygen, affords a proper supply of that most necessary element, to those parts of the earth in which, from the diminished intensity of the sun's light, it is obtained less abundantly by the decomposition of carbonic acid, produced there by combustion, respiration, &c. And the days are longest, precisely at the time, during which the plant requires to decompose most carbonic acid. If an alkali is combined with carbonic acid, the latter can no longer be decomposed, by leaves, &c. At night, oxygen is absorbed by plants, to form carbonic acid with the crude carbon contained in their sap.—The evolution of carbonic acid, by the plant, is termed its "respiration." It is probably continual: although, on the whole, the volume of carbonic acid being diminished, the quantity absorbed, is greater than what is given out. The leaves, and other parts containing volatile oils which, by combining with oxygen change into resin, absorb the most of that element. Some plants, as the *cacalia ficoides*, are sour in the morning, acids having been formed by the absorption of oxygen; tasteless at noon; and bitter in the evening, from excess of hydrogen.

21. Fresh wood absorbs oxygen; dried wood, when moistened, changes oxygen into carbonic acid. Pure woody fibre consists of carbon, and the elements of water:—but wood generally contains a larger quantity of hydrogen, than would be sufficient, along with its oxygen, to form that fluid. The excess is supplied by the decomposition of water; and, therefore, more oxygen is evolved, than arises merely from the decomposition of carbonic acid. Those parts of the plant which are not green, expire carbonic acid—but never oxygen. The green colour of plants depends, to a great extent, on the presence of light: and without the latter, they are generally colourless. M. De Humboldt, however, found green plants growing in total darkness, at the bottom of one of the mines of Freybourg. Also, sea weeds, taken from the bottom of deep seas—and, therefore, it is likely, produced in total darkness—are often highly coloured. Plants, grown in the absence of light, sometimes contain peculiar substances.—The blanched shoots of the potato, formed in cellars, or beneath the soil, contain *solanine*, a poisonous principle, which disappears under the influence of light: its presence renders the unripe potato unwholesome. Light is found to impede the production of sugar, in certain circumstances.—The blanched portions of celery, if exposed to light, would be bitter.

The large leaves of beet, when it is intended for the manufacture of sugar, should be allowed to cover the ground : otherwise the amount of saccharine matter will be diminished.

22. Starch, from the elements of which it consists ($C_{12}H_{10}O_6 + 2HO$), may be considered as formed, directly, by the union of water with the carbon of the decomposed carbonic acid : and may be looked upon, as the first substance, elaborated by the plant. The external coatings of the grains of starch would, if deprived of water, become lignine ($C_{12}H_6O_3 = C_{12} + 8HO$) :—and thus cells would be formed, the aggregate of which would constitute woody fibre. The change of starch, into other substances, may be traced, with equal facility—water, carbonic acid, &c., being given off. Starch is to the tree, what fat is to the animal—a magazine, whence the supply of future demands is intended to be taken. With this difference, however, that the starch is a source of increase ; while the fat merely supplies the carbon [inorg. chem. 177] and hydrogen, expended in producing vital heat, &c.

23. The minute portions of salts, present in the sap, perform very important functions, in the changes which occur. The alkalies are particularly necessary, since organic acids will not be generated, unless they are present. One of the greatest advantages of fallowing, arises from the action of the atmosphere producing further disintegration of the elements of the soil, and thus rendering a fresh quantity of alkali soluble. All ashes, obtained from plants, contain carbonates derived from the organic acids, which were united with bases in the plant. In different circumstances, plants of the same species may contain different oxides : but the total amount of atoms, depends on the number of atoms of organic acids. That is, the amount of oxygen, in the sum of the bases, will always be the same :—for the amount of oxygen in the bases, and their saturating power [inorg. chem. 31], always correspond. Liebig has shown, that the total amount of bases, in a plant, never varies—the excess of one always making up, precisely, for the deficiency of another. Iron, and manganese, are found in the bark of plants : but never, as the constituent of an organ.

In exogenous plants, the elaborated sap descends between the liber and alburnum : and new liber, and alburnum, are formed.

24. Like animals, plants require air :—the smallest seed, or the egg of the most minute insect, becomes unproductive in vacuo. The richest mould will not secure a plant from death, if atmospheric air is not allowed access to it. The free admission of air to the soil, and to the roots of plants, is one of the advantages of ploughing, &c. And, so well were even the ancients acquainted with the utility, of turning up the soil, that, when Cato was asked what was necessary for proper tillage, he

answered—"first, to plough well; second, to plough well; third, to manure." Nearly all the gases, except atmospheric air, are injurious, or even fatal to plants:—but cyanogen is the most destructive of all.

25. A certain amount of heat is necessary, both for animals and plants; and has, therefore, by various means, been secured to them. The excess of animal heat is carried off, by perspiration; and its diminution is supplied, by internal organization [inorg. chem. 171]. The imperfect conducting power of the earth, preserves an equable temperature to the roots of plants.—It is so bad a conductor of heat, that at 100 feet under its surface, the mean temperature—in England 52° , and in Cairo 70° —is always maintained.

26. THE FLOWER of a plant is, generally, composed of a variety of parts; all of which, however, are not essential to the functions it performs.

The *pistil*, or female organ, is ordinarily in the centre, and single: this is not the case, however, invariably—the rose has several pistils. The pistil consists of an *ovary*,* situated in its base, and containing the rudiments of the future seeds: of a *stigma*, which surrounds it, and receives the pollen; and of a *style*, which connects the ovary and stigma, but which—as in the poppy and tulip—is sometimes wanting. The *stamens* are the male organs, of which there are most commonly several, placed around the pistil. They consist of a *filament*,† surmounted by the *anther*, which contains the *pollen*, or principle of fecundation—a substance, to the naked eye, resembling dust. The filaments of the stamens are, in certain instances, absent: in others, they cohere, so as to form a tube—as in the thistle. When the stamens are shorter than the pistil, the flowers will be seen to hang in an inverted position. Outside the stamens, are found the *floral integuments*; the inner of these is called the *corolla*; and its parts are termed *petals*.‡—When it consists of only one petal, it is said to be *monopetalous*;§ when of two, *dipetalous*;|| when of many, *polypetalous*.¶ The stamens of the wild rose—which has only five petals—are changed, by cultivation, into petals: but it becomes barren. The external floral integument is called the *calyx*;** and its parts, *sepals*:—the flower being according to circumstances, called *monosepalous*, *disepalous*, &c. Whatever is outside the calyx—as the *floral leaves*—is not considered part of the flower. Sometimes—as in the tulip—one floral integument is wanting; sometimes, both. The whole of the floral integument, whether simple, or double,

* *Ovum*, an egg. Lat.

† *Petomai*, I expand the wings. Gr.

‡ *Dis*, twice. Gr.

** *Kalux*, the case which encloses the flower, bud, or fruit. Gr.

† *Filum*, a thread. Lat.

§ *Monos*, alone. Gr.

¶ *Polus*, many. Gr.

is called by Linnæus the *perianth*.* If the latter consists of but one floral integument—as in monocotyledonous plants—whatever may be its colour, it is called a calyx. If the flower has no flower stalks, it is *sessile*; but if it has, it is *peduncled*.† If the peduncle is branched, each branch is called a *pedicle*, and has a separate flower:—the flower of the pink is said to be peduncled, and that of the lilac, to be pedicled. In many cases, there are small leaves, different from the others, around one or more flowers; these are called *bractæ*:‡—if they greatly resemble the ordinary leaves, they are called floral leaves. The bractæ and floral leaves, sometimes form an *involucre*,§ or *accessary integument*—as in the anemone. When there are pedicles, if there is a small involucre at the base of each, it is called a *partial involucre*, or *involucellum*—as in the carrot. When the involucre consists of three bractæ, it is called *tryphyllous*;|| when of four, *tetraphyllous*,¶ &c. When the flower contains both male, and female organs, it is said to be *hermaphrodite*. When the male and female flowers are on the same plant, it is *monœcious***—as in the hazel. When they are on different ones, it is *diœcious*††—as in the paper mulberry. When male, female, and hermaphrodite flowers are formed on the same plant, it is *polygamous*‡‡—as in the crosswort. The pollen is transferred from the anthers to the stigmata, by simply falling from one to the other; by the winds; by insects; and sometimes, artificially, by man.

27. THE FRUIT is the ovary fecundated, and increased. It is divided into the *pericarp*,§§ and the seed. The pericarp consists of a thin membrane, called the *epicarp*,||| which covers the outside; of an internal membrane, next the seed, termed the *endocarp*;¶¶ and, between the epicarp and the endocarp, of a fleshy part, called the *sarcocarp**** or *mesocarp*.††† which is, sometimes, highly developed—as in the peach. The endocarp is frequently osseous, and forms a stone or nut, which, in many cases, is thickened by a portion of the sarcocarp—as in the cherry. Sometimes the endocarp is reflected inwards, so as to form *dissepiments*,‡‡‡ or divisions. The *placenta*,§§§ or *trophosperm*,|||| is that part of the pericarp to which the seeds are attached. The *arillus* is a prolongation of the placenta.

* *Peri*, around; and *anthos*, a flower. Gr. † *Pes*, a foot. Lat.

‡ *Brakūs*, short. Gr.

§ *Involucrum*, a covering. Lat.

|| *Tris*, three; and *phullon*, a leaf. Gr.

¶ *Tetra*, from *tessares*, four; and *phullon*. Gr.

** *Monos*, alone; and *oikos*, a house. Gr.

†† *Dis*, twice; and *oikos*. Gr. ‡‡ *Polūs*, many; and *gamos*, marriage. Gr.

§§ *Peri*, around; and *carpos*, fruit. Gr. ||| *Epi*, upon; and *carpos*. Gr.

¶¶ *Endon*, within; and *carpos*. Gr. *** *Sarz*, flesh; and *carpos*. Gr.

††† *Mesos*, middle; and *carpos*. Gr. ‡‡‡ *Septum*, an enclosure. Lat.

§§§ *Placenta*, a cake. Lat.

|||| *Trepho*, I nourish; and *sperma*, seed. Gr.

28. Fruit, until it is ripe, or nearly so, produces the same change on the atmosphere, as the leaves. The mode in which it ripens, may be exemplified by the apple.—This is at first tasteless, consisting of loose woody fibre, containing starch. ($C_{12}H_{20}O_9 + 2HO$.) The latter, by absorbing oxygen from the atmosphere, becomes tartaric acid ($C_8H_4O_{10}$)—four atoms of carbonic acid, and seven atoms of water, being disengaged. ($C_{12}H_{20}O_9 + 2HO + O_{14} = C_8H_4O_{10} + 4CO_2 + 7HO$.) The tartaric forms malic acid ($C_8H_4O_8$):—and, if this occurs during the time oxygen is given off by the plant, two atoms of oxygen are set free; but if, during the time carbonic acid is evolved, six atoms of tartaric acid, form five atoms of malic acid, eight atoms of carbonic acid, and four atoms of water. In the former case, $C_8H_4O_{10} = C_8H_4O_8 + O_2$; and, in the latter, $6C_8H_4O_{10} = 5C_8H_4O_8 + 8CO_2 + 4HO$. Sugar ($C_{12}H_{22}O_{11}$) is produced by starch, or lignine, combining with the elements of water.

29. THE SEED consists of the *episperm*,* or proper integument, and of the kernel—which is within the episperm. The point, by which the seed is connected with the pericarp, is called the *umbilicus*, or *hilum*. The episperm protects the seed from the too direct action of water: and serves as a filter, to admit only minute earthy particles;—it is, sometimes, very thick, and double. The kernel, or *nucleus*, contains, in many cases, merely the *embryo*—as the kidney bean; in others, also an accessory body, called the *endosperm*†—as wheat: this is intended for the nourishment of the embryo. The latter is the rudiment of the future plant, and is called, when there is an endosperm, *endospermic*, and when there is not, *epispermic*. The embryo consists of a *radicle*—which is to form the root; of the cotyledonary body—or nutriment; of a *gemmule*, formerly called the *plumule*—which is the rudiment of the parts that are to appear above ground; and of the *caulicle*‡—which is often imperceptible, being confounded with the radicle, or cotyledon. The cotyledons are, sometimes, by the growth of the caulicle, raised above ground, and are then termed *epigei*;§ otherwise, they are *hypogeï*.|| When the seed has only one cotyledon or lobe, it is said to be *monocotyledonous*; when two, *dicotyledonous*; when many, *polycotyledonous*. Monocotyledons produce a single leaf, by germination; dicotyledons two:—when the cotyledons are epigean, they form the seminal leaves.

30. The different parts of the seed are rendered perceptible, by germination, and are very distinct in the common garden bean. Its cotyledons or lobes are seen, when the two external coverings are stripped off. The small round white body which protrudes

* *Epi*, upon; and *sperma*, seed. Gr.

† *Caulos*, a stem. Gr.

|| *Hupo*, under; and *gē*. Gr.

† *Endon*, within; and *sperma*. Gr.

§ *Epi*, upon; and *gē*, the earth.

between the lobes, is the radicle: and attached to this, but between and entirely within the lobes, is the plumule, another small round body. If, after the latter has grown a little, the cotyledons are removed, the plant will live; but it will be stunted in growth. If they are taken away, before the plumule is developed, the plant will die—even though the radicle has become a root. Air is necessary to the seed, since, while it is germinating, oxygen is required to form sugar—carbonic acid and, no doubt caloric being evolved. Moisture also is indispensable, and a certain amount of heat. But, while it is in the ground, light must be entirely, or almost entirely, excluded from it. Vast quantities of nutriment are absorbed by the seed—the great effort of nature appearing to be, its production by the plant. Hence, another reason [12] why green crops exhaust the earth, less than grain crops.

31. PECULIARITIES OF ORGANIC ELEMENTS, AND THEIR COMPOUNDS.—They are, almost always, more complicated than those which belong to inorganic chemistry:—like the latter, they enter into combination with each other, and with the more simple substances. They form acids, and bases, with oxygen, and sulphur; and some of them, hydracids, with hydrogen. In which case, as with the inorganic acids, their hydrogen is evolved [inorg. chem. 25]; or, combining with the oxygen of an oxide, it forms water.

32. Organic elements often consist of certain *radicals*, united with other substances. Some of these radicals are known; the existence of others is inferred, with great probability; and there are others, no doubt, which, as yet, are altogether unknown.—The doctrine of compound radicals has, already, very much simplified our chemical knowledge; and, when more fully developed, will lead to its still further advancement. Should the same group of elements be found in a number of compounds, which are produced merely by the change, or interchange, of other elements more weakly united than those of the group, it is very reasonable to consider that group, as itself an element. This may be extremely well illustrated, by oil of bitter almonds ($C_{14}H_6O_2$).—If the latter is supposed to consist of a radical $C_{14}H_5O_2$ (which has been termed *Benzyle*; *ymb.* Bz) united with an atom of hydrogen, a number of compounds, intimately connected with each other, will be obtained, by merely changing the atom of hydrogen, for oxygen, chlorine, &c. Thus Benzoic acid ($C_{14}H_5O_3 = C_{14}H_5O_2 + O$) will be formed, from hydruret of benzyle (oil of bitter almonds), by replacing the atom of hydrogen with an atom of oxygen, &c. The justness of such a view is confirmed by the fact, that oil of bitter almonds may, with little difficulty, be reproduced from the new combinations. I have already mentioned [inorg. chem. 310] that certain compounds, belonging

to inorganic chemistry, are supposed to have a compound radical.

33. In some instances, a portion of the radical, itself, is replaced. Thus $C_4H_6O_2$ constitutes alcohol; $C_4H_6S_2$ mercaptan. The sulphur, and oxygen compounds are, in such a case, analogous. If the hydrogen of acetylene (C_2H_2) is replaced by chlorine, acetyl chloride (C_2Cl_2), a new radical, is obtained. The combinations of such corresponding radicals, also, give rise to analogous compounds; and, if they are broken up, by means of affinities still stronger than those which hold them together, they will produce corresponding results. Thus, $C_4H_5O_3 + HO$ (hydrated acetic acid) heated with potash, will give $2CO_2 + C_2HH_3(2CO_2 + 2CH_2)$; and $C_4Cl_3O_3 + HO$ (chloroacetic acid) decomposed, in the same way, will give $2CO_2 + C_2HCl_3$.* A portion of the elements constituting the compound radical may, in the formation of a new radical, be removed. Thus the hypothetical ethylene (C_2H_2), deprived of two atoms of hydrogen, becomes acetylene (C_2H_2).

34. When an organic substance is acted upon, by dry chlorine, the latter sometimes replaces more or less of the hydrogen belonging to the body: at others, it removes hydrogen and forms, with it, free hydrochloric acid. When water is present, along with the chlorine, its hydrogen goes to the chlorine, and its oxygen to the organic substance.—Generally speaking, however, some of the chlorine combines with the oxygen; and, in the form of hypochlorous, or chlorous acid, unites with the organic substance.

35. Nitric acid, in some instances, merely gives oxygen to the organic body; but, most frequently, the oxygen, at the same time, replaces some of its hydrogen. The nitrogen, nitrous oxide, or nitric oxide of the nitric acid may, also, enter into combination.

36. When chlorine, or oxygen, takes the place of hydrogen, new radicals—which are sometimes more simple—will be produced. Thus, if to aldehyde ($C_4H_3O + HO$), six atoms of chlorine are added, the result will be chloral ($C_4Cl_3O + HO$), and three atoms hydrochloric acid. But, if five atoms of the hydrogen of alcohol ($C_4H_6O_2$), are replaced by oxygen, the result will be two atoms of oxalic acid ($2C_2O_3$) and six atoms of water. When the organic compound does not contain nitrogen, it is changed, by oxygen, into the oxides of more simple radicals. Thus, alcohol ($C_4H_6O_2$) and two atoms of oxygen, become aldehyde ($C_4H_3O + HO$) or hydrated oxide of *acetylene* and two atoms of water. Oxalic acid (C_2O_3) and oxygen, become two atoms carbonic acid ($2CO_2$).

Substances, which belong to the same class, form compounds,

* Chloroform.

that bear the same relation to each other, as exists between themselves. Thus, wine alcohol ($C_4H_6O_2$) gives acetic acid ($C_4H_3O_3$); methylic or wood alcohol ($C_2H_4O_2$) formic acid (C_2HO_3); oil of potato spirit ($C_{10}H_{12}O_2$) or amylic alcohol, valerianic acid ($C_{10}H_9O_3$); and ethal ($C_{82}H_{34}O_2$), cetylic acid ($C_{32}H_{31}O_3$).—Each acid has one atom more oxygen, and three atoms less hydrogen, than the corresponding alcohol.

37. Sulphuric acid acts sometimes, catalytically [inorg. chem. 135]; at others, it combines, unchanged, with the organic body. If it is decomposed, an atom of its oxygen, along with an atom of the hydrogen of the organic body, form water; and the resulting sulphurous, along with an atom of undecomposed sulphuric acid, enters into combination, as hyposulphuric acid.

38. When an organic body is fused with potash, it is broken up, into simpler compounds; or, it is oxidated, water being decomposed, and hydrogen evolved.—At high temperatures, carbonic acid is always produced.

39. If the organic body contains nitrogen, when it is decomposed by strong acids, by being boiled with caustic potash—or fused with its hydrate—water is generally decomposed, and ammonia formed. If the decomposition is effected by potash, ammonia is disengaged, and oxide of the new radical combines with the potash. Should the substance be very rich in nitrogen, some of the latter may, along with oxygen, form cyanic acid (C_2NO), which will combine with the potash, and produce a compound that, by dissolving in water, is changed into carbonate of ammonia and carbonate of potash. $(C_2NO + KO) + 4HO = (CO_2 + NH_4O) + (CO_2 + KO).$

40. Organic combinations, subjected to destructive distillation, are decomposed into more simple compounds—carbon being, sometimes, deposited. The nature of the results will, however, be modified by the temperature employed. During the first period of the distillation, organic acids of the more simple radicals, carbonic acid, water, and combustible fluids—miscible with water—are produced. In the second period, the compounds, formed during the first, are decomposed; the oxygen of the acids unites with part of their hydrogen and carbon, forming water, carbonic oxide, carbonic acid, &c. A portion of the carbon is, generally, deposited: and another portion uniting with hydrogen, forms fixed, or volatile, oleaginous substances. The products of the last period are almost always carbonic oxide, olefiant gas, and light carburetted hydrogen.—If certain bases are present, they will be found, afterwards, in combination with carbonic acid.

41. Organic bodies, containing nitrogen, when subjected to destructive distillation, produce ammonia—and, sometimes, cyanic acid; but, ultimately, cyanogen, and hydrocyanic acid.

I now proceed to examine the most important organic substances. They are not easily classified.—I will therefore place them in the order which suggests itself as either the most natural or, under the circumstances, the most convenient.

42. OXALIC* ACID:—*symb.* C_2O_3 , or \bar{O} ; *equiv.* 36. It was discovered, by Scheele, in 1776. It is found in the sorrel, and many other plants:—also, combined with lime, in concretions of the human body; and, with oxide of iron, in a mineral substance. It may be formed, with great facility, from all organic compounds which do not contain nitrogen, by oxidizing their elements, with nitric acid.—If nitrogen were present, ammonia would be produced at the same time. Berthollet procured half its weight of oxalic acid, from wool, by heating it with nitric acid. It is conveniently obtained, by digesting, with a gentle heat, one part sugar—or, what is better, potato starch—and five parts nitric acid, specific gravity 1.42, diluted with ten parts water. Four-fifths of the dilute nitric acid are to be added, at first; and the remaining fifth, when the action has become moderate. The sugar would be changed into oxalic acid, by removing the hydrogen, and replacing it, with oxygen. $C_{12}H_{11}O_{11} + O_{18} = 6C_2O_3 + 11HO$. But, as saccharic acid, and other substances, are formed, along with the oxalic acid, the process is somewhat more complicated. When gaseous products are no longer evolved, the liquid is to be evaporated. This will cause the oxalic acid to separate, as colourless transparent crystals—which, if the crystallization is rapid, are in the form of small irregular needles. They must be purified, by solution, recrystallization, and drying with bibulous paper, or porous earthenware. On being heated, they give off their two atoms water of crystallization, and the hydrate, containing a single atom, remains, in the form of a white powder.

43. Oxalic acid is without odour, but its taste is strongly acid, even when dissolved, in a considerable quantity of water:—its solution in 30,000 times its weight of that fluid, will redden litmus paper. It is decomposed, when heated in a retort to 310° , into formic acid (C_2HO_3), carbonic acid, and carbonic oxide, without any residue. If heated rapidly, in open vessels, part of the acid is decomposed: and another part sublimes, unchanged—the fumes being irritating, and producing a cough. Heated with strong sulphuric acid, it is decomposed, as I have already described [*inorg. chem.* 263]. Heated with peroxide of manganese, it is changed into carbonic acid, one atom of which combines with the resulting protoxide. $MnO_2 + C_2O_3 = (CO_2 + MnO) + CO_2$. It is doubtful whether it should be considered as belonging to organic or inorganic chemistry.

* *Oxalis*, sorrel. *Lat.*

Binoxalate of potash $[(C_2O_3+KO)+(C_2O_3+HO)+2Ag]$ —sold under the name of “essential salt of lemons,” is used for removing iron moulds, and other metallic stains, from linen.

44. Oxalic acid is a violent poison. It has been, sometimes, mistaken for Epsom salts (SO_3+MgO) . But the sour taste of the acid, and the bitter taste of the salt, should be quite sufficient to distinguish them. Carbonate of lime (chalk), or of magnesia, is the antidote for oxalic acid, since the oxalate of lime, being insoluble, is inert: the carbonate should be administered after, if possible, the poison has been expelled, by an emetic.

45. All the oxalates are decomposed, at a red heat, the oxalic acid being resolved into carbonic acid, and carbonic oxide: of which the former combines with the base, if it is an alkali, or an alkaline earth. When the base is metallic, if the metal is easily reduced, it is left in the metallic state; if not, as an oxide.

46. Oxalic acid may be known, by giving, with lime water, and solutions of the soluble salts of lime, even when very much diluted, a white oxalate soluble in nitric, and in hydrochloric acid. It gives, with chloride of barium, a white oxalate, insoluble, in nitric, or hydrochloric acid. With nitrate of silver, a white oxalate, which dissolves in nitric acid, and in ammonia.

47. Carbonic oxide [inorg. chem. 263] is supposed to be the radical of this acid, and to form compounds, with various elements. Thus—

With oxygen, oxalic acid,	$2CO+O$
With hydrogen, mellitic acid,	$4CO+H$
And croconic acid,	$5CO+H$
With chlorine, chloro-carbonic acid,	$CO+Cl$
With the radical of ammonia, oxamide,	$2CO+NH_2$
With potassium, oxy-carburet of potassium,	$7CO+3K$
With water, rhodezonic acid,	$7CO+3HO$

48. CYANOGEN:—*symb.* C_2N , or *Cy*; *equiv.* 26·02. This substance, which is one of the compound radicals, was discovered by Gay Lussac. It does not exist ready formed in nature; but is very easily generated from bitter almonds, the kernels of peaches, plums, &c. It is produced, synthetically, in a variety of ways.—When nitrogen is passed over a mixture of potash and charcoal, ignited together in a tube, cyanide of potassium (*CyK*) is formed, and carbonic oxide is evolved. $3C+KO+N=(C_2N+K)+CO$. It is very conveniently procured, by saturat-

* *Cuanos*, agure; and *gennao*, I produce, *Gr.*; because the chief constituent of Prussian blue.

ing a moderately dilute solution of prussic acid, with peroxide of mercury, evaporating the resulting solution of percyanide ($CyHg$) to dryness, and heating it in a green glass retort:—the mercury is reduced to the metallic state, and cyanogen is evolved.

49. Cyanogen is a colourless gas, of a penetrating odour, and irritating to the eyes. Its specific gravity is 1·819:—100 cubic inches weigh 56·4103 grains. It burns, with a rose-coloured flame. It is condensed into a colourless liquid, at a pressure of about four atmospheres. Water, at 60°, absorbs 4·5 volumes, and alcohol, 23 volumes, of this gas. The aqueous solution reddens litmus paper—on account of acids, produced by the decomposition both of water, and of the cyanogen.

50. It forms with oxygen, cyanic acid (CyO ; 34·02), which is monobasic, and is obtained only as a hydrate: fulminic acid (Cy_2O_2 ; 68·64), which is bibasic; and cyanuric acid (Cy_3O_3 ; 102·06), which is tribasic. With hydrogen, hydrocyanic (CyH ; 27·02), or prussic acid. With chlorine, chloride of cyanogen ($CyCl$; 61·49); and *solid* chloride of cyanogen (Cy_3Cl_3 ; 184·47). With iodine, iodide of cyanogen (CyI ; 152·87). With bromine, bromide of cyanogen ($CyBr$; 105·99), &c.

51. Cyanogen combines with the various metals. Cyanides of the bases of alkalies and of alkaline earths, are soluble: and are decomposed by acids—including the carbonic. But they are not decomposed, by ignition, if atmospheric air is excluded. Most cyanides of the heavy metals are insoluble: many of them are not decomposed, by dilute oxacids, nor by strong nitric acid—except with difficulty: but nearly all of them, easily, and perfectly by hydrochloric, and hydrosulphuric acids. All are decomposed, by ignition, into cyanogen and a metal, if they are cyanides of the noble metals: but, if not, into nitrogen and carburets.

52. The cyanides of the heavy metals, though insoluble, combine with the soluble alkaline cyanides.—Thus cyanide of gold is dissolved, by cyanide of potassium. The insoluble cyanide is precipitated, from such a combination, by an acid—the soluble cyanide being decomposed. If any of these double cyanides, in solution, is mixed with the solution of a salt of a heavy metal, a new double cyanide is produced—the alkaline being replaced by its equivalent of the heavy metal.

53. HYDROCYANIC, OR PRUSSIC* ACID:—*symb.* C_2NH , or CyH ; *equiv.* 27·02. It was discovered by Scheele: and was carefully examined, by Gay Lussac. It is a constituent of the water, distilled from the leaves, and blossoms, of several stone fruits, &c.: and is produced by them, in such quantity, that instances

* Because first obtained from *Prussian blue*.

are on record of persons having been poisoned by liqueurs, manufactured from them.—For the same reason, an incautious use of bay-leaf in cookery, has been attended with fatal results. It is a product of the destructive distillation of many substances, containing nitrogen.

54. *Anhydrous Hydrocyanic Acid* may be obtained in a variety of ways:—but, very economically, by distilling, at a gentle heat, a mixture containing three parts yellow prussiate of potash ($\text{FeCy}_3 + 2\text{K}$) in fine powder, two parts oil of vitriol, and two parts water: and conveying the product, into a well-cooled receiver, containing five parts fused chloride of calcium, in tolerably large pieces. The results are hydrocyanic acid, Everet's salt ($2\text{FeCy} + \text{KCy}$), and bisulphate of potash. $2(\text{FeCy}_3 + 2\text{K}) + 6(\text{SO}_3 + \text{HO}) = 3\text{CyH} + (2\text{FeCy} + \text{KCy}) + 3[(\text{SO}_3 + \text{KO}) + (\text{SO}_3 + \text{HO})]$. The former salt is yellow: but, by absorbing oxygen, and abandoning its cyanide of potassium, it becomes greenish, and then blue—being changed into *basic* ($3\text{FeCy} + 2\text{Fe}_2\text{Cy}_3 + \text{Fe}_2\text{O}_3$) Prussian blue. $9(2\text{FeCy} + \text{KCy}) + \text{O}_3 = 2(3\text{FeCy} + 2\text{Fe}_2\text{Cy}_3 + \text{Fe}_2\text{O}_3) + 9\text{KCy}$. When the chloride of calcium is covered with the fluid, it is poured off into a well-stopped bottle.

55. Anhydrous prussic acid, is a colourless liquid. Its odour resembles that of peach blossom—which arises from its presence. Its specific gravity, at 77° , is 0.6969. It congeals into a fibrous mass, at 5° : when absolutely anhydrous, it is said not to congeal till -64° . It boils, at 80° , which, it should be remembered, is sometimes the temperature of the atmosphere, in summer. If not quite anhydrous, it volatilizes so rapidly in the air, as to become solid. It is highly combustible—burning with a white flame. Concentrated mineral acids, change it into formic acid (C_2HO_3), and ammonia—water being decomposed. $(\text{C}_2\text{N} + \text{H}) + 3\text{HO} = \text{C}_2\text{HO}_3 + \text{NH}_3$. Light decomposes it into ammonia and a brown substance—the constitution of which is not known with certainty: but the decomposition is prevented, by small quantities of mineral acids.

56. It is a most violent poison.—When pure, if a rod is dipped in it, and applied to the tongue of an animal, death ensues before the rod can be withdrawn. According to Liebig, its action on the blood is far more powerful, than on the stomach.—A cat will swallow two or three drops of anhydrous acid, diluted with about six ounces of water, without being at all affected. And two drops may be placed on her tongue without any injury, as long as she is not allowed to breathe:—but she dies, the very instant she respire. Ammonia, and chlorine, are antidotes for prussic acid; but, being themselves very deleterious substances, they must be used [inorg. chem. 246, and 329] with great caution. When the acid is at all strong, death

occurs so rapidly, that no antidote can be administered, in sufficient time.

57. *Hydrous Hydrocyanic Acid* may be obtained, by distilling, from a bath of chloride of calcium, four parts crystallized ferrocyanide of potassium, two parts oil of vitriol, and eighteen parts water. The condensing apparatus ought to be of glass: and the vapours should be received into a vessel, containing twenty parts water—the process being stopped, when they have become thirty-eight parts.

58. Allowing for its being diluted with water, it is similar, in its properties, to the anhydrous. Its taste is bitter, and acid. It is liable to spontaneous decomposition: and the more so, in proportion as it is weaker.—Hence it is impossible to keep it, at a given degree of strength. From this cause, it has frequently happened that, while the last portion of one bottle of the acid might, without any inconvenience, be administered to a patient in certain doses; the same amount of a new portion, nominally of the same strength, would produce very dangerous effects. The strength of a given acid may be ascertained, by the quantity of cyanide of silver, precipitated by means of nitrate of silver, from a certain quantity of it. The experiment must be made with the greatest care, and a very delicate balance must be used.—The cyanide of silver should be dried, at a moderate temperature, and weighed. One hundred grains of an acid containing three per cent. of the anhydrous should give 11.98 grains of cyanide.

59. Hydrocyanic acid, and the cyanides, in solution, are known by giving, with nitrate of silver, a white precipitate (AgCy).—The latter is soluble in cyanide of potassium: it emits, when moistened with hydrochloric acid, the characteristic odour of hydrocyanic acid; and, when acted upon by heat, it leaves metallic silver, as residue. They give, with acetate of lead, a white precipitate (PbCy). With protosulphate of iron—which, from exposure to the air, has part of its iron peroxidated—a blue precipitate ($3\text{FeCy} + 2\text{Fe}_2\text{Cy}_3 = 3\text{FeCy}_3 + 2\text{Fe}_2$), provided potash is present. It is evident there must be, both protoxide and peroxide, that the cyanide, and sesquicyanide may be formed, by their decomposition:—potash is required, on account of the prussic acid not being able, by itself, to decompose the sulphate. The precipitate will be of a dirty green colour, until the excess of oxides of iron, thrown down by the potash, is dissolved by adding hydrochloric acid: after which—according to the quantity of hydrocyanic acid present—there will be either a fine blue precipitate (Prussian blue), or a blue liquor. Sulphate of copper gives, when potash and hydrochloric acid are added, in the same way, and for similar reasons, a white precipitate. If some of a liquid,

containing free hydrocyanic acid, is placed in a watch glass : and another watch glass, in which is a drop of hydrosulphuret of ammonia—with excess of sulphur [inorg. chem. 253]—is inverted over it for a few minutes, sulphocyanide of ammonia ($\text{CyS}_2 + \text{NH}_4$) will be formed, on gently evaporating the drop of hydrosulphuret, to dryness ; and, on adding it to the solution of a persalt of iron, a beautiful blood red colour—due to the presence of persulphocyanide of iron ($\text{Fe}_2 + 3 \text{CyS}_2$)—will be produced. The warmth of the hand may be used, to accelerate the rising of the hydrocyanic vapour, from the lower watch glass. This test is due to Liebig : and is sufficiently delicate, to detect the 473rd of a grain of prussic acid, in ten drops of liquid. The most decided test for prussic acid, is its dissolving peroxide of mercury—even though potash, in excess, is present.

60. Insoluble compounds, containing cyanogen, may be known, by heating them with a little potash, and sulphur : then adding the solution of a persalt of iron.—The blood red sulphocyanide will be formed.

61. *Urea* :— $\text{C}_2\text{N}_2\text{H}_4\text{O}_2$. When cyanic acid is placed in contact with dry ammonia, a woolly mass (supposed to be $\text{CyO} + 2\text{NH}_3 + \text{HO}$) is the result. If this is heated, it evolves ammonia, and the residue is *urea*, a very important constituent of urine—being sometimes secreted, by a single individual, to so large an amount as 500 grains, in twenty-four hours.

Urea may be obtained, from urine :—but, more conveniently, by mixing, in powder, twenty-eight parts dry ferrocyanide of potassium, with fourteen parts peroxide of manganese, and calcining, at a low red heat. When the mass has ceased to glow, it must be allowed to cool ; after which, the cyanate of potash, which has been formed, is to be dissolved out, fully, with cold water ; and the solution is to be mixed with 20·5 parts sulphate of ammonia. The latter, at first, throws down some sulphate of potash :—but careful evaporation to dryness, causes the formation of urea, which, being dissolved out by boiling with alcohol, will separate from the alcoholic solution, on cooling. Urea is in the form of colourless four-sided prisms, that are very soluble in water. It fuses at 250° ; but a high heat decomposes it—ammonia, cyanic, and cyanuric acids, being formed. It is isomeric with cyanate of ammonia ($\text{C}_2\text{NO} + \text{NH}_4\text{O}$) ; but is not considered identical with it.

62. URIC ACID, $\text{C}_{10}\text{H}_4\text{O}_6\text{N}_4$; *equiv.* 230·12. It was discovered by Scheele ; and is found in the urine of all carnivorous animals, of birds, reptiles, and of many insects. In combination with urea, it is deposited from human urine, on cooling, as a brownish, or yellow powder. The urine of serpents, or of birds, and guano—the decomposed excrement of aquatic birds—consists almost entirely of urate of ammonia. The stone-like concretions, in

the joints of gouty persons, contain urate of soda—or of ammonia: and uric acid is the basis of most calcareous deposits, in the human bladder. It may be obtained, by boiling pulverized urinary calculi, or the excrements of the larger kinds of serpents, with caustic potash: and precipitating the resulting urate of potash, with hydrochloric acid, in excess. Uric acid will be thrown down, in the form of brilliant, white, silky-looking scales: which are to be boiled in water, washed, and dried.

63. Uric acid has neither colour, taste, nor smell. It is slightly soluble, in boiling water. It dissolves in sulphuric acid—from which, however, the addition of water precipitates it. When it is digested with nitric acid, carbonic acid, and nitrogen are evolved; and, if the solution, which contains ammonia, with a number of other substances, is evaporated to dryness, and ammonia, in excess, is added to the residue, a beautiful purple red colour will be produced. When uric acid is fused with hydrate of potash, carbonic acid, cyanate of potash, and cyanide of potassium are the results. Uric acid is decomposed, by heat, into urea, hydrocyanic acid, carbonate of ammonia, &c.

64. Uric acid is supposed to be derived from a radical termed *uryle* ($C_2O_3 + Cy$)—or cyanoxalic acid. It consists of an atom of oxalic acid, having one atom of oxygen replaced by cyanogen; or, in other words, it is a combination of carbonic oxide—the radical [47] of oxalic acid—and cyanogen. It would enable us to express, very simply, the constitution of a number of compounds.—Thus uric acid would be two equivalent of uryle, combined with one equivalent of urea [61], &c.

65. Cyanogen, by combining with different metals [51], produces new radicals. With iron it forms *ferrocyanogen* ($FeCy_3$, or Cfy ; 106·06)—which is known, in combination with hydrogen, as hydroferrocyanic acid ($FeCy_3 + H_2$, or $Cfy + H_2$; 108·06), or *ferrocyanide of hydrogen*, a bibasic acid. It is capable of having its two atoms of hydrogen replaced by the same, or different metals. Thus, when they are replaced by potassium, ferrocyanide of potassium ($Cfy + 2K$) or “yellow prussiate of potash,” is the result. If a solution of this salt is mixed with a concentrated solution of a salt of iron, calcium, manganese, &c., each atom of the potassium is exchanged for an atom of iron, calcium, manganese, &c.: ferrocyanides of these metals being produced. Cyanogen is supposed, also, to form the radical *ferridcyanogen* ($Fe_2Cy_3 = Cfy_2$, or $Cfdy$; 212·12)—isomeric with ferrocyanogen, but having a double atomic weight. It is found, in combination with hydrogen, as hydroferridcyanic acid ($Fe_2Cy_3 + H_2$; 215·12), or *ferridcyanide of hydrogen*, a tribasic acid, which is capable of having its three atoms of hydrogen replaced, also, by the same, or different metals. Thus, when they are replaced by potassium, the result is ferridcyanide of

potassium ($\text{Fe}_2\text{Cy}_6 + 3\text{K}$) or red prussiate of potash. Other modes of expressing the composition of the complicated cyanides have been proposed; but the above seems natural, and sufficiently simple. Cyanogen forms, with platinum, platino-cyanides; with cobalt, cobalti-cyanides, &c. With sulphur, sulpho-cyanides.

66. *Ferrocyanide of potassium*, or yellow prussiate of potash ($\text{Cfy} + 2\text{K}$). That of commerce is sufficiently pure. When this salt is fused with carbonate of potash [inorg. chem. 622], the result contains also a cyanate—which however does not affect it, as a re-agent. $2(\text{FeCy}_3 + 2\text{K}) + (\text{CO}_2 + \text{KO}) = 2\text{Fe} + 5\text{CyK} + (\text{CyO} + \text{KO}) + \text{CO}_2$. The cyanate, on adding water, is [39] immediately decomposed.

67. *Ferridcyanide of potassium*, or red prussiate of potash ($\text{Cfdy} + 3\text{K}$), may be obtained, by dissolving one part ferrocyanide of potassium of commerce in ten parts water, and transmitting chlorine through the liquid, until it is no longer capable of giving a blue tint to a drop of the solution of perchloride of iron. It is then to be concentrated by evaporation, and carbonate of potash is to be added, until there is a slight alkaline reaction. After which, having been filtered and allowed to cool, beautiful red crystals of the salt will separate.

68. *Sulphocyanide of potassium* ($\text{CyS}_2 + \text{K}$) may be obtained, by mixing—extremely well—forty-six parts of anhydrous [66] ferrocyanide of potassium, with seventeen parts carbonate of potash, and thirty-two parts sulphur: then fusing the mixture in an iron pan with a cover, at a gentle heat, until the whole is clear and calm. The hyposulphite of potash that has been formed is then decomposed, by increasing the heat to faint redness. After which the mass, having been half cooled, is crushed in pieces and boiled with alcohol. Part of the salt will separate in colourless crystals on cooling the resulting solution: and the remainder may be had, by distilling off the alcohol.

69. ACETIC* ACID:—*ymb.* $\text{C}_4\text{H}_3\text{O}_3$, or $\bar{\text{A}}$; *equiv.* 51. As *vinegar*,† acetic acid has been known from the earliest times: but, was first obtained, as hydrated acid, by Löwitz in 1793. It is derived from various sources. All liquids, capable of the *vinous* fermentation—that is, of having alcohol produced in them—may change their alcohol, by oxidation, into acetic acid: but, pure alcohol does not, by exposure to the air, become acid. When fermentation is carried on at a low temperature, as in the manufacture of *Bavarian* beer, the liquid loses the power of becoming acid, even at a higher temperature: on account of

* *Acētum*, vinegar. *Lat.*

† *Vin aigre*, sour wine. *Fr.*

the *fermenting matters* employed, having been altered into insoluble substances, and removed.

70. *Vinegar* may be obtained, by adding to an infusion of malt, which has previously undergone the vinous fermentation, a little sour dough, or some other "ferment." It is manufactured, in wine countries, by mixing inferior wines that have become sour, with a little vinegar, and exposing them to the air, in casks partly filled with the husks of grapes. The addition of brandy, during the process, causes the vinegar to be of a proper strength.

71. In the manufacture of vinegar, free access of air is of deep importance.—Spongy platinum will become red hot, in a mixture containing vapour of alcohol, and common air; so rapidly will acetic acid be formed. Hence, the time required for manufacturing vinegar, is greatly shortened, by exposing a large surface of fluid to the atmosphere, and thus facilitating the oxidation of the alcohol. The liquor, therefore, which is intended to be acetified, is, in the improved process—after being warmed to between 75° and 83° —made to trickle through a mass of shavings, steeped in vinegar; and the action of the atmosphere, soon causes the temperature to rise as high as 100° , or even 104° . After the liquid has passed three or four times, through the shavings, the operation is complete. During manufacture, three atoms of hydrogen are taken from the alcohol, and one atom of oxygen is absorbed. When atmospheric air is not supplied in sufficient quantity, it merely abstracts two atoms of hydrogen from the alcohol, and forms *aldehyd* ($C_2H_4O_2$) or *hypo-acetous acid*: which, being volatile, flies off before it has combined with the two atoms of oxygen, required to change it into hydrated acetic acid: and thus waste is produced.

Alcohol cannot be acetified, if any essential oil, or pyroligneous acid, is present.

72. *Pyroligneous* Acid*.—If wood is subjected to destructive distillation, a vinegar is obtained, which is charged with tar: but it is freed from the latter, by rectification, and neutralization with soda. Since it does not, like that obtained from wine, beer, &c., contain acetic ether, and is even contaminated by *kreosote*,† and other substances—produced by destructive distillation of wood—its flavour is not so agreeable. But, it has, on account of the kreosote, such strong antiseptic properties, that meat—to which it will impart a pleasant smoked taste—may be preserved with it.

73. *Hydrated Acetic Acid* can be procured, by mixing, in a large retort, one part, by weight, of finely powdered acetate of soda—obtained from the neutralized pyroligneous acid—and

* *Pūr*, fire, *Gr.*; *lignum*, wood. *Lat.*

† *Krēas*, flesh; and *sōzo*, I save. *Gr.*

three parts strong oil of vitriol. The heat, which arises from mixture, causes one-eighth of the acetic acid to distil over of itself: and the process, is completed, by the application of a lamp, &c. The last portion of the product, exposed to a temperature below 40° , deposits, crystals of hydrated acid—which, being separated from the rather weaker portion, melted with the aid of heat, cooled, and recrystallized, may be considered as pure.

Three parts dried acetate of lead, and eight parts oil of vitriol, treated in the same way, give the same results.

74. Hydrated acetic acid, cooled below 62° , crystallizes in transparent colourless broad scales, and tables. Above 62° it forms a liquid, the specific gravity of which is 1.063: and its density increases, by the addition of water, until it becomes 1.078. It then contains three equivalents ($C_4H_3O_3 + 3Ag$): and further dilution diminishes its specific gravity. Hence, the latter is no test of its strength:—indeed, acids of very different strengths, may have the same specific gravity. The hydrated acid boils at 240° , and its vapour is inflammable: it fumes in a damp atmosphere, and attracts moisture. It mixes with any quantity of water, alcohol, ether, and essential oils: and dissolves camphor, several resins, &c.—*Aromatic vinegar* is acetic acid holding camphor, or essential oils, in solution. Acetic acid is blackened by sulphuric acid—heat being evolved, and sulphurous acid disengaged. When acted upon by chlorine, under the influence of the sun's rays, it forms *chloroacetic acid* ($C_4Cl_2O_3 + Ag$). If its vapour is passed through a porcelain tube, heated to low redness, carbonic acid, and *acetone* (C_3H_3O), are at first produced: and, when the temperature is raised, inflammable gases—carbon being deposited.

Anhydrous acetic acid has not yet been obtained.

75. If acetic is adulterated with sulphuric acid, the latter will be detected by nitrate of barytes [inorg. chem. 309]. If it contains nitric acid, it will give a yellowish colour to indigo, when boiled with that substance: and, if tartaric acid, it will, with nitrate of silver, throw down a precipitate, soluble in nitric acid. Ordinary vinegar, almost always contains traces of sulphuric, and tartaric acid.

76. The neutral acetates—but not free acetic acid—give, with nitrate of silver, white crystalline precipitates ($\bar{A} + AgO$), which dissolve freely in ammonia, and sparingly in cold water. Acetic acid and, still more, solutions of the acetates give, with protonitrate of mercury, a white scaly protoacetate ($\bar{A} + HgO$), soluble in excess:—it dissolves, also, in hot water, but, is reprecipitated, by cooling, in the form of small crystals. The latter have a gray colour, on account of the protoacetate having been partially decomposed, metallic mercury being liberated.

Acetic acid, disengaged from the acetates, with sulphuric acid, may be very easily recognised, by its penetrating odour. If it is heated with equal parts strong sulphuric acid and alcohol, acetic ether ($\bar{A} + C_4H_5O$) will be evolved—and may be known by its agreeable smell. The acetates are decomposed, at a red heat, the residue being sometimes a metal, and, at others, an oxide:—if the acetate is alkaline, it is changed to a carbonate, and in all cases, carbon is liberated.

77. *Acetylene* (C_2H_2 , or Ac)—not yet obtained—is supposed to be the radical of this acid: and to form various compounds. Thus—

Oxide of acetylene,	C_2H_2O , or AcO —hypothetical
Hydrate of the oxide of acetylene, or aldehyd,	$C_2H_2O + HO$, or $AcO + HO$
The hydrogen of aldehyd, replaced by chlorine, gives chloral,	$C_2Cl_2O + HO$
Aldehyd, with an atom of oxygen, gives hydrated acetous or aldehydic acid,	$C_2H_3O_2 + HO$, or $AcO_2 + HO$
Acetous acid, with an atom of oxygen, gives hydrated acetic acid,	$C_2H_3O_3 + HO$, or $AcO_3 + HO$.

78. *FORMIC* ACID*:—*ymb.* C_2HO_3 , or FoO_3 ; *equiv.* 37. It was discovered, by the red colour of endive, found in the nest of the *red ant*: Gehler first recognised it as a distinct acid; and Dobereiner first prepared it artificially. It may be procured from ants: and it is one of the products of the distillation of vegetable substances with nitric, iodic, periodic, or permanganic acid; or, with a mixture of chromic and sulphuric acids and peroxide of manganese. It may be conveniently obtained by mixing one part starch, or sugar, with four parts black oxide of manganese, four parts water, and four oil of vitriol. Since the carbonic acid is disengaged so as to cause great effervescence, a retort large enough to hold ten times as much as the mixture, should be used: and the sulphuric acid should be added gradually—the starch (or sugar) manganese and water, having been heated to 104° . When the frothing has ceased, heat is again applied; and, four and a half parts having distilled over, the acid liquor is boiled with carbonate of lead. On cooling, crystals of formiate of lead ($FoO_3 + PbO$) will separate. They are to be dried and powdered: and then introduced into a long glass tube, one end of which is connected with a receiver, and the other with an apparatus for disengaging sulphuretted hydrogen. As soon as the formiate of lead

* *Formica*, an ant: on account of the source whence it was formerly obtained.

has become perfectly black, it is entirely decomposed : and the hydrated formic acid may be driven into the receiver, by a *very* gentle heat :—the excess of sulphuretted hydrogen is to be expelled, by boiling. If the acid liquor is neutralized with carbonate of soda, instead of lead, and concentrated, crystals of formiate of soda will separate : and formic acid may be disengaged from them, by sulphuric acid, in the same manner as acetic acid is obtained [73] from acetate of soda.

79. The formic acid, obtained in this way, is combined with an atom of water. It is a clear, colourless, and very caustic liquid, of a penetrating odour : it fumes slightly, and attracts moisture from the atmosphere. Its specific gravity is 1.235. Cooled below 32° , it crystallizes in brilliant scales : it boils at 212° ; and its vapour is inflammable—burning with a blue flame. It mixes with any quantity of water ; but an additional atom changes it to the second hydrate ($\text{FoO}_3 + 2\text{HO}$). The specific gravity of the latter is 1.1104 : it may be cooled below 5° , without solidifying ; and it does not boil, till 223° . This hydrate may be made, by distilling, in a chloride of calcium bath, eighteen parts dry formiate of lead, six parts oil of vitriol, and one part water. Like the other, when placed on tender parts of the skin, it causes wounds that are cured with difficulty.

80. Concentrated solutions of alkaline formiates give, with nitrate of silver, a sparingly soluble white crystalline precipitate ($\text{FoO}_3 + \text{AgO}$), which, on being heated, immediately becomes dark, from the presence of metallic silver. $\text{C}_2\text{HO}_3 + 2\text{AgO} = 2\text{CO}_2 + \text{HO} + 2\text{Ag}$. Similar results would be obtained, with protonitrate of mercury. These reductions are perceived, also, in solutions of formic acid, and dilute solutions of alkaline formiates—although a formiate of the metal is not thrown down. If formic acid is heated with excess of peroxide of mercury, or peroxide of silver, carbonic oxide, and water, are formed—the metallic oxide being reduced. Boiling causes the whole of the silver, or mercury, to assume the metallic state. This enables us to distinguish formic, from acetic acid ; and to separate the latter—since it affords acetates, which remain in solution. Like the acetates [76], the formiates are decomposed by a red heat—the residue being, according to circumstances, a metal, an oxide, or a carbonate.

81. *Formyle* (C_2H , or Fo)—not yet obtained—is supposed to be the radical of this acid : and to produce various compounds. Thus—

Oxide of formyle,	.	.	.	C_2HO , or FoO —hypothetical
Hydrated formic acid,	.	.	.	$\text{C}_2\text{HO}_3 + \text{HO}$, or $\text{FoO}_3 + \text{HO}$
Protochloride of formyle,	.	.	.	C_2HCl , or FoCl
Bichloride of formyle,	.	.	.	C_2HCl_2 , or FoCl_2

Perchloride of formyle, or

“chloroform,” C_2HCl_3 , or $FeCl_3$

Hydrochlorate of chloride of

formyle, $2C_2HCl + HCl$, or $2FeCl + HCl$

Periodide of formyle, . . . C_2HI_3 , or FeI_3

Perbromide of formyle, . . . C_2HBr_3 , or $FeBr_3$

Sulphuret of formyle, or

“sulphoform,” probably, . C_2HS_3 .

82. TARTARIC* ACID :—*ymb.* $C_8H_4O_{10}$, or \bar{T} ; *equiv.* 132. It was first obtained by Scheele: and is supposed to have been the earliest discovery of that celebrated Swedish chemist. It is found in the juice of the grape, in the tamarind, and sumac, in sago, and in many fruits—particularly, when they are not too ripe. Combined with potash, it forms “tartar,” the hard incrustations, perceived on the lower sides of the barrels in which several species of wine are kept—especially those of France, of the Moselle, and of the Rhine.

83. Tartaric acid is procured, by adding one part lime, to four parts cream of tartar ($2\bar{T} + KO$) dissolved in water:—tartrate of lime is precipitated, and neutral tartrate of potash ($\bar{T} + KO$) remains, in solution. The latter is decomposed, with chloride of calcium—which throws down the remainder of the tartaric acid, in combination with lime. The tartrate of lime, is collected, washed, and digested with oil of vitriol, equal in weight to half that of the cream of tartar employed, and diluted with four parts water. After the mixture has boiled, for a while, it is strained, and gently evaporated to a pellicle.—The tartaric acid will crystallize on cooling, unless tartrate of lime, or free sulphuric acid is present. The crystals are colourless if pure. When brown, they are decolourized, by animal charcoal.

84. Tartaric acid is bibasic:—the crystals contain two atoms of water. It does not change, by exposure to the air. It is soluble in alcohol; and dissolves in half its weight of water, forming a very acid solution, which becomes mouldy by keeping:—if it is long exposed to the air, or is boiled with oxide of silver, in excess, it absorbs oxygen, and forms carbonic and acetic acids. A strong solution of caustic potash, at a high temperature, changes it into acetic, and oxalic acids, which combine with the potash. $C_8H_4O_{10} = C_4H_2O_3 + 2C_2O_3 + HO$.

85. The presence of tartaric acid, in solutions containing certain metallic oxides, prevents precipitation by alkalies—on account of tartrates, not decomposed by alkalies, being formed. It acts in this way, with alumina, peroxide of iron, protoxide of manganese, &c.

* On account of being obtained from “tartar:” so called from the *Tartarus* of mythology—because this salt is deposited on the lower parts of the cask.

86. Tartaric acid is often used, in medicine, &c.—*Sedlitz powders*—or “carbonated effervescing Cheltenham salts,” consist of tartaric acid, and bicarbonate of soda, in the proportions of their atomic weights. Sometimes a little sulphate of magnesia (Epsom salt), or tartrate of potash and soda (Rochelle salt) is added.

87. Chloride of calcium throws down, from solutions of neutral tartrates, a white precipitate ($\overline{T} + \text{CaO}$), the separation of which is retarded, by the presence of ammoniacal salts. A solution of caustic potash, keeps tartrate of lime in solution, while it is hot, but abandons it when cool. Tartrate of lime is precipitated by lime water, from solutions of the neutral tartrates—or even from tartaric acid, if enough to produce an alkaline reaction is added. Free tartaric acid, gives a sparingly soluble bitartrate, with caustic potash [inorg. chem. 622]: and, still more readily, with acetate of potash.

88. When tartaric acid is cautiously heated, it becomes *tartralic acid* ($\text{C}_{12}\text{H}_6\text{O}_{15} + 2\text{HO}$),—an amorphous mass like gum, which, after a while, again becomes tartaric acid. If it is kept, a considerable time, at a temperature of 360° , it becomes *tar-trellic acid* ($\text{C}_{16}\text{H}_8\text{O}_{20} + 2\text{HO}$) which, unlike tartralic, forms insoluble salts with lime, and barytes. A still longer continuation of the heat, produces *anhydrous tartaric acid* ($\text{C}_8\text{H}_4\text{O}_{10}$)—a porous white mass, which is insoluble in water, or alcohol: and changes—gradually, by contact with water, but rapidly by boiling with caustic potash—into tartrellic, tartralic, and, ultimately, tartaric acid. Raised to the temperature of 400° , tartaric becomes *pyrotartaric acid* ($\text{C}_8\text{H}_2\text{O}_8$), water and carbonic acid, being produced. $\text{C}_8\text{H}_4\text{O}_{10} = \text{C}_8\text{H}_2\text{O}_8 + \text{HO} + 3\text{CO}_2$. Pyrotartaric acid is monobasic.

89. *RACEMIC** ACID, called, also *paratartralic*, has the same constitution, and nearly the same properties, as tartaric acid.

It has been found, only about the Vosges mountains—and, even there, but occasionally. It occurs as biracemate of potash, which, like the bitartrate, is a very sparingly soluble salt. It is bibasic, and its crystals contain four atoms of water. It differs from tartaric acid, in forming, with lime, a compound, which is insoluble in tartaric acid, or sal-ammoniac.—Also, the neutral paratartrates, unlike the neutral tartrates, give a precipitate, with gypsum. Racemic acid is changed, by heat, precisely in the same way as the tartaric, except that pyroracemic acid is $\text{C}_8\text{H}_2\text{O}_8$. The corresponding results of both acids have, however, different properties.—A crystal of protosulphate of iron, becomes of a bright red colour, in the solution of a pyroracemate.

90. *CITRIC*,† ACID:—*symb.* $\text{C}_{12}\text{H}_8\text{O}_{11}$ or $\overline{\text{Ci}}$; *equiv.* 165. It was

* *Racēmus*, a bunch of grapes. *Lat.*

† *Citreum*, a lemon. *Lat.*

first accurately described, by Scheele in 1784—being, until his time, confounded with tartaric acid. It is found in many fruits, but most abundantly—along with sugar, mucilage, acetic, and a small quantity of malic acid—in the lemon: and may be obtained, by straining lemon juice, heating it nearly to the boiling point, gradually adding pulverized chalk in excess, and boiling until the citrate of lime completely separates. The supernatant fluid—which contains the mucilage—is then removed; and, the citrate, after being washed on a filter—to take away the sugar, &c.—is decomposed with oil of vitriol, equal in weight, to the chalk which has been used, and diluted with six times its volume of water. If the resulting solution of citric acid, having been filtered from the sulphate, is concentrated to a pellicle, at 212° , it will afford, while hot, crystals which contain three atoms of water. If they are produced, by evaporation at a lower temperature, and slow cooling, they will have two additional atoms: but will lose them, by exposure to a gentle heat, or by being placed in vacuo, with oil of vitriol.

91. Citric acid is bibasic. It is sparingly soluble in alcohol: but it dissolves in less than its weight of cold, and in half its weight of boiling water:—the solution, however, like that of tartaric acid [84] will not keep. It has an agreeably sour taste: and is much employed in medicine.—It has been found of great value, in preventing sea scurvy, so destructive to mariners, in long voyages: and is used, in “effervescing drafts,” to disengage the carbonic acid from the carbonate of soda. For this purpose, one part citric acid, and nineteen parts water, afford an excellent substitute for the juice of a lemon—particularly, if a little sugar, and a few drops of the oil of lemons, are added. Citric, being one of those acids, which form a soluble compound with oxide of iron, it is often employed to remove “iron moulds” from linen, &c. It is very much used, by calico printers: and is, sometimes, adulterated with tartaric acid—which may be discovered, by dissolving it, in water, and slowly adding a solution of carbonate of potash. If tartaric acid is present, the sparingly soluble bitartrate [87] will precipitate.

Citric, like tartaric acid [85], prevents some metallic oxides from being precipitated, by potash.

92. Neutral citrates, in solution—but not free citric acid—give, with chloride of calcium, a white citrate ($\overline{Ci} + CaO$), which is soluble in sal-ammoniac, unless boiled with it; in which case, basic citrate [$(\overline{Ci} + 3CaO + CaO) + A_7$], is thrown down. Citric, is distinguished from almost every other organic acid, by affording, whether free, or in combination, if boiled with lime water, a basic citrate, which is redissolved, when the liquor cools. Acetate of lead, in excess, gives, with citric acid, a precipitate

($\bar{C}i + PbO$), soluble in citrate of ammonia. And citric acid, in excess, gives, with acetate of lead, a precipitate, which dissolves on adding ammonia, because citrate of ammonia is formed. Citric acid, and the citrates, acted on, at a high temperature, by sulphuric acid, in excess, produce carbonic oxide, and carbonic acid, at first: but after some time, the fluid becomes discoloured, and sulphurous acid is evolved.

93. When citric acid is heated till a pellicle forms, a new acid, the *aconitic** ($C_{12}H_5O_9 + 3HO$), is produced, along with *acetone* (C_3H_5O), and a mixture of carbonic oxide and carbonic acid.—The same acid is found, in combination, as aconitate of ether ($C_{12}H_5O_9 + C_4H_5O$), when citric acid and alcohol, are acted upon, with sulphuric acid. If aconitic acid is boiled, carbonic acid is evolved, and *itaconic* acid ($C_{10}H_4O_6 + 2HO$) passes over, and crystallizes, on cooling. When itaconic acid is redistilled, water, and *citraconic* acid ($C_{10}H_5O_6 + HO$) are produced:—the latter, placed in contact with water, combines with another atom of that fluid.

94. MALIC† ACID:—*symb.* $C_4H_4O_6$, or \bar{M} ; *equiv.* 116. Malic acid exists, to a considerable amount, in the juice of apples, which owe their sourness, chiefly, to it; and is found, more or less abundantly, in other fruits—such as the plum, currant, blackberry, raspberry, strawberry, cherry, &c. It is contained, also, in the berries of the mountain ash; but was, at first, called *sorbic acid*,‡ when derived from that source, being considered an acid, distinct from the malic. It may be obtained, by nearly saturating the juice of the berries of the mountain ash, with lime; boiling the liquor, for some hours, to precipitate the malate of lime: and, when the latter ceases to be thrown down, adding a little lime—to complete the precipitation. The whole of the malate is obtained on cooling: and is to be dissolved, by boiling in as little dilute nitric acid as possible. Malate of lime will separate, in crystals, when the temperature falls: and having been purified, by re-crystallization, it is to be decomposed by acetate of lead. When the resulting malate of lead is acted upon, with sulphuretted hydrogen, sulphuret of lead, and malic acid will be obtained. The latter is evaporated, and forms, on cooling, a syrupy liquor which, after resting some time, becomes a white crystalline mass.

95. Malic acid is bibasic: and, in the formation of salts has a great tendency to retain one atom of basic water. It is without odour, but is extremely acid to the taste: it is deliquescent, and very soluble, in water.

96. Solutions containing malic acid, either free, or combined,

* On account of having been found in the *aconitum napellus*.

† *Malus*, an apple tree. *Lat.*

‡ From *sorbus aucuparia*, the mountain ash.

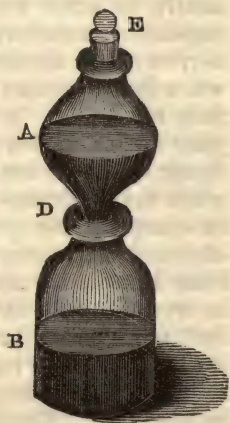
give with chloride of calcium, on adding alcohol, a white malate ($\overline{M} + \text{CaO}$). Acetate of lead throws down a white malate ($\overline{M} + \text{PbO}$) remarkable for melting in the water in which it is suspended, at a less temperature than 212° : and then appearing like resin, fused under that liquid. This property is impaired, or destroyed, by the presence of other salts of lead. Malic is distinguished from the tartaric, racemic, citric, and oxalic acids, by giving no precipitate with lime water—even when heat is applied.

97. If malic acid is heated to 400° , it loses its water: and forms two acids, which are isomeric ($\text{C}_6\text{H}_8\text{O}_6$). One of them, the *maleic*, passes over in distillation, along with the water, and crystallizes on cooling:—it has been supposed identical with aconitic acid [93]. The other, *fumaric acid*,* remains in the receiver, and cools into a crystalline mass. It is found in Iceland moss: and gives, with nitrate of silver, a precipitate soluble in nitric acid—but so insoluble in water, that it will be thrown down from that fluid, when it contains only the 200,000th part fumaric acid. If hydrochloric acid gas is passed into malic acid and alcohol, fumaric, and not malic, acid is found in combination with ether.

FIG. 345.

98. TANNIC ACID OR TANNIN:—*symb.*

$\text{C}_{12}\text{H}_8\text{O}_9$, or $\overline{Q}t$;† *equiv.* 185. This substance was long known, under the name of *astringent* principle. It is found in dried grape seed, in the bark of all perennial trees—and, indeed, to a greater or less extent, in all trees, and shrubs. It is very abundant in the oak, and horse chestnut; but its principal source is the gall-nut of the former. It may be obtained, by putting powdered nut-galls, and some ether of the shops—because it contains water—in a globular funnel A, fig. 345, having a stopper E, and terminating, below, by a tube in which some cotton has been placed, and which rests in the neck of the bottle B. After some days, the tannic acid, will be found in B, dissolved in the water, which was associated with the ether:—the latter floats above, and contains a trace of tannic, and gallic acids. The aqueous solution, having been washed, two or three times, with ether, is placed under an exhausted receiver; and the result will be a yellowish white crystalline mass, consisting of tannic acid, combined with three atoms of water.



* Because first found in the *fumaria officinalis*.

† Because effective in the conversion of skin into leather.

‡ The *acidum quercitanicum*:—from *quercus*, an oak. *Lat.*

99. Tannic acid is tribasic. It is not deliquescent; but it dissolves in water with great facility. It is soluble in alcohol, and ether—unless, perhaps, when they are quite anhydrous. It forms an insoluble, imputrescible precipitate, with a solution of glue, or isinglass:—this precipitate is *leather*. Tannic acid may exist, in a combination, from which gelatine will not liberate it, without the addition of a dilute acid.

Tannic acid in solution, exposed to the air, absorbs oxygen, evolves carbonic acid, and becomes coloured—gallic acid being produced.

100. Tannic acid is very important, as a test: and is generally used as “infusion,” or “tincture, of galls.” The colour obtained by means of this acid and iron is particularly valuable to the dyer; when very intense it is nearly black. Tannate of iron, suspended in a solution of gum, constitutes writing ink.—If ink becomes, gradually, of a darker colour, it rises from the peroxidation of the iron, and the consequent formation of an additional quantity of tannate. The tannic acid of some plants produces, with iron, a green combination.

As tannic acid forms an insoluble and, therefore, inert compound with antimony, it is often used as an antidote to “tartar emetic” (tartrate of potash and antimony: $C_8H_4O_{10} + SbO_3 + KO + 2Ag$).

101. Artificial tannin may be obtained, by mixing one part of any vegetable substance, with five parts oil of vitriol: letting the mixture rest for some days; then heating it, as long as sulphurous acid is evolved: afterwards washing away the acid, from the residual black mass, with water: finally drying the result, dissolving out the tannin with alcohol, and evaporating the dark brown solution. An extractive matter remains, which has an astringent taste, dissolves in water, and precipitates gelatine—but not the salts of iron. Artificial tannin may be formed, also, by boiling carbon in nitric acid, evaporating the solution, to a syrup, mixing the latter with water, filtering and evaporating;—the residue, a hard, black mass, which is soluble in water and alcohol, contains nitrogen, and precipitates most of the metallic salts, brown. A decoction of coffee berries, after being roasted, gives tannin, formed, probably, or developed during the roasting.

102. MANUFACTURE OF LEATHER. The first part of the process consists in removing the hair from the skins.—This is facilitated, by incipient putrefaction, caused by a smouldering fire, kept up in the apartment along with them; or by the action of lime. They are, then, impregnated with the tanning principle contained in oak bark, &c. This is effected, either by leaving them for some time in a pit containing bark and water, layers of ground bark having been placed between them; or, by

steeping them in water holding the "tanning principle" in solution. A weak liquor must be used, at first: or, the surface of the skin becoming impervious, the interior will not be tanned. Skins are tanned much more rapidly, by the latter process; but the leather produced, is believed not to be so durable. The greater the quantity of extractive matter which, along with tannic acid, enters into combination with the leather, the better.

Bodies remain undecomposed, in bogs, for a long time; being preserved by the antiseptic properties of the tannic acid:—they undergo changes, somewhat analogous to the alteration produced in the skin by tanning.

103. *Tawing* is very different from tanning. Skins are "tawed," by being impregnated with a mixture of alum and common salt. The latter, causes alumina to combine with the gelatine—which decomposes the chloride of aluminum, at first formed. They are next, put to ferment, in a vessel containing bran and water; then dried, and finished. A white, and flexible leather is obtained by this method.

104. **GALLIC* ACID**:—*ymb.* C_7HO_3 , or \overline{G} ; *equiv.* 67. It has been found in nature, ready formed, only in the seeds of the *mango*; but it may be procured from a great variety of sources. It was long known that infusion of galls, oak bark, shell of the walnut, &c., are capable of giving a black precipitate with salts of iron; but the nature of the substance, which produced this effect, was not understood, until the academicians of Dijon in 1772 pronounced it to be an acid. The mode of separating it, from the other substances, found along with it, was not discovered for a considerable time after Scheele, in 1780, published a method of obtaining gallic acid.—He conceived it to exist in galls; and was not aware that a new acid was formed, during the process he employed.

105. Gallic acid is generated, by the decomposition of tannic acid, oxygen being absorbed, water formed, and carbonic acid evolved. $C_{18}H_3O_9 + O_8 = 2C_7HO_3 + 3HO + 4CO_2$. For this purpose, a thin paste, consisting of powdered galls and water, is exposed to the air, for some weeks, at a temperature of about 80° —the fluid evaporated, being occasionally replaced. The mass is then boiled with water; and, on cooling, gallic acid will separate from the liquor, in the form of crystals. The latter, being digested at a moderate temperature with ivory black, and re-crystallized, are colourless. Gallic acid may be obtained, in other ways, more easily, and rapidly, but not in such a state of purity.

106. It is a bibasic acid. Its taste is sour and astringent. The crystals contain three atoms of water, one of which is

* Thus named, because it was obtained abundantly from nut-galls.

removed by a temperature of 230° , and the others, only by bases. They dissolve in their own weight of hot alcohol, in three times their weight of hot, and 100 times their weight of cold water. Gallic acid reddens litmus paper; but, although it decomposes many salts which contain a powerful acid—sulphate of the peroxide of iron, for example—it is unable to expel the carbonic acid, from carbonate of barytes.

107. Unlike tannic acid, it does not throw down gelatine. It gives, with persalt of iron, a blackish blue precipitate, which becomes colourless, by degrees—on account of the decomposition of the acid, and reduction of the iron to protoxide, carbonic acid being evolved. This change is caused, at once, by boiling. An alkaline solution of gallic acid, exposed to the air, absorbs oxygen, and becomes yellow, green, red, brown, and lastly, almost black.

108. When gallic acid is heated to 400° it is decomposed into *pyrogallic* ($C_6H_3O_3$), and carbonic acids. If it is heated to 450° , water is given off, and *melangallic* acid* ($C_{12}H_3O_3$), in the form of a shining black substance, is produced. It is altogether decomposed at 500° .

109. The mass, from which the gallic acid was dissolved out [102] will be found to contain *ellagic acid* ($C_7HO_3 + HO + Aq$). It may be obtained, by digesting with potash, and precipitating with hydrochloric acid. It is one of the constituents of the *bezoar* stones of India, the intestinal concretions of certain animals. Gallic acid—but not ellagic acid—heated with oil of vitriol, gives, on cooling, *parellagic acid*. It is in the form of dark crystals: and has the same constitution as ellagic acid.

* *Melas*, black. Gr.

CHAPTER VII.

Constituents, &c., of Oils and Fats, 110.—Glycerine, 113.—Stearic Acid, 116.—Margaric Acid, 123.—Oleic Acid, 126.—Butter, 133.—Spermaceti, 137.—Wax, 139.—Soaps, 140.—Manufacture of Soap, 145.—Resin, 149.—Caoutchouc, 155.—Gutta Percha, 158.—Starch, 159.—Lichenine, 163.—Gum, 164.—Sugar, 167.—Lactine, 176.—Mannite, 178.—Diastase, 179.—The Vinous Fermentation, 181.—Brewing, 185.—Distillation, 191.—Alcohol, 194.—Ether, 203.—Manufacture of Bread, 210.—Lignine, 214.—Gun Cotton, 215.—Extractive Matter, 218.—Gluten, 219.—Vegetable Albumen, 221.—Legumine, 222.—Fibrine, 223.—Animal Albumen, 224.—Caseine, 227.—Vegetable Jelly, 231.—Gelatine, 232.—Ozmazome, 234.—Vegetable Alkalies, 235.—Salicine, 236.—Caffeine, or Theïne, 238.—Piperine, 240.—The Putrefactive Fermentation, 241.—Last Products of decaying Vegetable Matter, 254.

110. CONSTITUENTS, &c., OF OILS, AND FATS.—The fixed, are distinguished from the volatile oils, by being incapable of distillation, without being decomposed. Fixed oils, and fats, are compounds of *glycerine*, the oxide of *glyceryle* ($C_6H_7O_4$; *ymb.* *Gly*), with, generally speaking, the *stearic*, *margaric*, and *oleic* acids: the stearate, margarate, and oleate of glycerine being termed, respectively, for the sake of brevity, *stearine*, *margarine*, and *oleine*. Fixed oils, and fats, are found, principally, in the cellular membranes of animals; in the seeds, capsules, and the pulp surrounding the seeds of plants. All of them, when fluid, leave a permanent greasy stain on paper. Acids decompose them, by combining with their glycerine; and alkalies, by setting it free—a soap being formed. Stearine causes the fat to be firm, and solid; when margarine predominates, it imparts the consistence of lard; but, when oleine is in excess, fat assumes the liquid form. Sometimes, these three substances are present, at the same time; but never, less than two of them. Human fat, goose fat, and olive oil, contain only margarine, and oleine. Unless a volatile oily acid—such as the *butyric*, or *hircic*—in combination with the oxide of glycerule, is present, fixed oils, and fats, are almost always without smell. When they are rendered impure, by the presence of mucus, albumen, &c., they become rancid, by the absorption of oxygen, and the production of, probably, an acid—since it is removed by alkalies.

111. Oils, and fats, are divided into those which do not dry when exposed to the air, and those which, by absorbing oxygen, and again giving out some of it as carbonic acid, become a dry, tough, and transparent varnish.—Olive oil, almond oil, rapeseed oil, &c., belong to the former: and linseed oil, poppy-seed oil, nut oil, &c., to the latter. They dry much more rapidly, if their impurities are destroyed by boiling: particularly if litharge is added: or, what is still better, if they are agitated with water, litharge, and sub-acetate of lead—for their impurities will then subside, and a little oxide of lead will be retained, which improves them. The litharge combines with, and coagulates, vegetable mucus, which would prevent the oil from drying so quickly. Fish oils, in some respects, resemble the drying oils; but they contain one or more oily acids—generally the *phocenic*.

112. Drying oils, when exposed on a large surface—such as shavings, wool, cotton, &c., absorb oxygen so rapidly, as often to produce spontaneous combustion. In this way, manufactories have been set on fire, by “cotton waste,” used to wipe the oil from machinery, &c. Fixed oils, and fats, are insoluble in water; but soluble in oil of turpentine, and to a certain extent, in alcohol, and ether. They dissolve sulphur, phosphorus, and generally speaking, iodine.

We are chiefly indebted to the admirable researches of Chevreul, for our knowledge of the real nature of oils and fats; and of their compounds.

113. GLYCERINE,* or the hydrated oxide of glycercyle:—*ymb.* $C_6H_5O_5 + HO$, or $\bar{G}lyO + HO$. It was discovered by Scheele: and may be obtained, by heating equal parts olive oil, and finely ground litharge, with a little water: and keeping the mixture well stirred. When it has assumed the consistence of a plaster, water being added, it is removed from the fire: and the liquid, after being decanted off, is freed from any lead it may contain, by transmitting sulphuretted hydrogen through it, and filtering. It is then concentrated as much as possible, in a water bath; and dried, *in vacuo*, with sulphuric acid.

114. Glycerine is a colourless syrup, which has never been solidified. Its specific gravity is 1.26. It is insoluble in ether; but dissolves in alcohol and water—which it even absorbs from the atmosphere. By combining with two atoms of sulphuric acid, it forms *sulpho-glyceric acid* ($C_6H_5O_5 + 2SO_3 + HO$).

115. Glycerine has not, in all circumstances, exactly the same constitution. But, if the glycerine of nutmeg butter (C_3H_5O) is taken as the true anhydrous glycerine, the others may be looked upon, as combinations, or hydrates of it.—Thus the glycerine of palm oil ($C_8H_7O_2$) may be two equivalents of the

* *Gluküs*, sweet, *Gr.*; since glycerine is the *sweet principle* of oils.

anhydrous; and the glycerine of ordinary fats, that of palm oil, plus three atoms of water. Berzelius would consider the glyceryle of nutmeg butter, as the oxide of a radical (C_8H_8 ; *ymb. Lp*), named by him *lipyle*.

116. STEARIC* ACID:—*ymb.* $C_{88}H_{66}O_5$, or \overline{St} . It was discovered by Chevreul, in 1811: and may be obtained, by saponifying, with potash, *stearine* (stearate of glycerine)—the residue, when mutton suet is washed with ether as long as any thing is dissolved; then precipitating the stearic acid by means of warm dilute hydrochloric acid, washing the precipitate with water, and dissolving it in boiling alcohol. The acid will separate from the latter, on cooling, in brilliant white plates: and is purified by repeated crystallization from hot alcohol.

117. Stearic acid is bibasic; and its crystals contain two atoms of water:—the *bi-stearates* consist of one atom of water, and one atom of fixed base; and the *neutral stearates* of two atoms of fixed base. It is without taste, or smell. When liquid, and at 170° , its specific gravity is 0.854. It congeals, at 158° , into a crystalline mass, the specific gravity of which is 1.01. It is insoluble, in water: but dissolves, in hot alcohol, and the solution reddens litmus paper.

118. In the cold, stearic acid partially decomposes the alkaline carbonates, forming a bicarbonate and an acid stearate: at a boiling temperature, it expels the carbonic acid, and forms a neutral stearate. The latter is decomposed, by 1000 parts water, into potash and the acid stearate—which is insoluble in water, but soluble in alcohol. If the acid stearate is removed, 1000 parts boiling water will change two atoms of it, into one atom of still more acid stearate ($2\overline{St} + KO + 3HO$), which remains suspended in the water, and an atom neutral stearate, which is dissolved by it.

119. Earthy, and metallic, soaps are insoluble:—the latter are termed *plasters*.

120. Stearic acid, under the influence of heat, seems to distil over unaltered, since it condenses into a substance, having nearly the same melting point.—It has, however, been entirely changed, *margaric acid* ($C_{34}H_{33}O_2$) and *margarone* ($C_{34}H_{33}O$), being produced. $2C_{88}H_{66}O_5 = 3C_{34}H_{33}O_2 + C_{34}H_{33}O$. If stearic acid is heated with an equal weight of nitric acid, specific gravity 1.25, for a few minutes, large quantities of red fumes are given off: and the stearic is entirely changed into margaric acid, oxygen being absorbed. $C_{88}H_{66}O_5 + O = 2C_{34}H_{33}O_2$. But if the process is continued, nitric acid being occasionally added, until the fat acid disappears, the liquid, on cooling, will deposit

* *Stear*, tallow. *Gr.*

*Succinic** acid ($C_4H_2O_3 + Aq$) as a mass of crystals. And, if the mother liquor, after the succinic acid has been removed, is evaporated to one-half, *suberic*† acid ($C_8H_6O_3 + Aq$) will separate, also, as a mass of crystals. The precise manner in which these acids are formed, is not, as yet, well understood.

121. When stearic acid is heated in contact with lime, *stearone* ($C_{46}H_{45}O$), a volatile liquid is produced.—The compound, obtained, in this way, by Redtenbacher, seems to be a combination of margarone with one ($C_{12}H_{12}$) of the many carbo-hydrogens, which have different equivalents, although their carbon and hydrogen are in the same proportions.

122. Large quantities of stearic acid are used in the manufacture of a species of candle, which is very little inferior to wax. The material of which it consists is obtained by saponifying tallow with lime, mixed with water so as to form a thin paste; then decomposing the resulting soap with hydrochloric acid, and removing the oleic acid, by pressure between folds of cloth. The tendency of the stearic acid, to crystallize, is counteracted—very improperly, however—by the addition of about one part in 2,000 arsenic.

123. MARGARIC‡ ACID.—*ymb.* $C_{34}H_{33}O_3$, or \overline{Mr} . It was discovered by Chevreul. To obtain it, the ethereal solution, decanted off in obtaining the stearine [116], is evaporated: and the residue is dissolved in boiling alcohol. *Margarine* (margarate of glycerine) will be deposited, in the crystalline form, on cooling. The process, used for obtaining stearic acid from stearine [116], enables us to procure margaric acid in the form of white needles, from margarine. Margaric acid may, also, as I have already mentioned [120], be obtained by oxidizing stearic, with nitric acid. Other oxidizing substances, would produce the same effect.

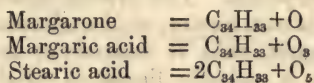
124. Margaric acid is monobasic: and its crystals contain one atom of water. It differs from stearic acid, by melting at 146° . If it is heated with, or without, lime, margarone ($C_{34}H_{33}O$), carbonic acid, a hydrocarbon ($C_{32}H_{32}$) and water, are produced. $2C_{34}H_{33}O_3 = C_{34}H_{33}O + 2CO_2 + C_{32}H_{32} + HO$. Margarone is a white crystalline friable fat, which may be purified by crystallization from ether.—It would appear to consist of two or more bodies, each having the same constitution: since, though it generally melts at 190° , its point of fusion is sometimes as high as 200° , or beyond it. If it is repeatedly distilled, from lime, the result is a carbo-hydrogen ($C_{66}H_{66}$), carbonate of lime, and carbon—which is deposited. $2C_{34}H_{33}O + CaO = C_{66}H_{66} + (CO_2 + CaO) + C$.

* *Succinum*, amber, *Lat.*; because obtained by the destructive distillation of that substance.

† *Suber*, cork, *Lat.*; because a product of the oxidation of cork, with nitric acid.

‡ From *margaritis*, a pearl. *Gr.*; on account of the appearance of margarate of potash.

125. It is more than probable that margarone, as also margaric, and stearic acid, are compounds of a radical ($C_{34}H_{33}$)—which has been termed *margaryle*. If such be the case, their constitution is—



That stearic, and margaric acids are compounds of the same radical, is rendered the more likely, by the facility with which the former is changed into the latter [120].

126. OLEIC* ACID :—*ymb.* $C_{36}H_{33}O_2$, or \overline{Ol} . Combined with glycerine, it is the principal constituent of liquid fixed oils, that are not “drying oils.” It is almost quite pure in almond oil; and rather less so, in rape oil. It is found, along with stearic acid, in bile. It may be obtained, by exposing the solution of almond oil in hot ether, to intense cold—which separates any margarine present, in the crystalline form: and, when the ether is driven off, from the clear liquor, by a gentle heat, the residue is oleine (oleate of glycerine), a compound which remains fluid, at 0° . The oleine is saponified, with a strong solution of caustic potash; and the oleate of potash decomposed with hydrochloric acid. The oleic acid, which separates, should be washed, and dried under an exhausted receiver, with chloride of calcium.

127. Oleic acid is monobasic: and is obtained in combination with an atom of water. It is an oily liquid, without colour, taste, or smell. Its specific gravity, at 68° , is 0.898. It dissolves in water; but, still more readily in alcohol, and ether—and the solutions redden litmus paper. At some degrees below 32° , it becomes a mass of needly crystals. The solubility of oleate of lead, in ether, enables us to separate it perfectly, from the stearate, or margarate, of that metal. If the ethereal solution of oleate of lead is mixed with dilute hydrochloric acid, the oleic acid, dissolved in ether, will rise to the surface.

128. When oleic acid is exposed to a high temperature, part of it distils over unaltered; but most of it is decomposed into a number of substances, of which the principal are *sebacic† acid* ($C_{10}H_8O_2$), carbonic acid, a carbo-hydrogen ($C_{59}H_{59}$), and carbon. $2(C_{36}H_{33}O_2 + HO) = C_{10}H_8O_2 + 2CO_2 + C_{59}H_{59} + C$.

129. When oleic acid is acted upon, with the red fumes of nitrous acid, a deep yellow butyraceous mass is produced. If this is digested, with warm alcohol, a deep orange red oil is dissolved: and the residue is *elaïdine*, a compound of *elaïdic acid* ($C_{72}H_{66}O_6$), and glycerine. When this is saponified, with caustic potash, a soap is produced, from which elaïdic acid,

* *Oleum*, oil. *Lat.*; from *elaion*, olive oil. *Gr.*

† *Sebaceus*, belonging to tallow. *Lat.*

combined with two atoms of water, is obtained, by means of hydrochloric acid. The manner in which the nitrous acid produces the orange red oil, and the elaidine, is not understood—the composition of the oil not being, as yet, ascertained.

130. Concentrated nitric acid acts so violently on oleic acid, as to produce almost an explosion: and it acts powerfully, at first, even when diluted. On applying heat, a small quantity of an oily fluid, which has a pungent smell, and attacks the organs of respiration, passes over—along with the vapours of nitric, and nitrous acid. If, when a fatty acid no longer separates on cooling, the solution is evaporated to one-half, it will deposit crystals of suberic [120], along with a small quantity of *azolaic acid* (supposed to be $C_{10}H_8O_4 + Aq$). These substances having been removed, and the liquor allowed to rest, for some time, more suberic acid will be deposited—and, also, *pimelic acid* ($C_7H_6O_3 + Aq$), in the form of hard crystalline grains. When these are taken away, and the mother liquor, after being gently evaporated, is allowed to rest for some days, crystals are deposited: and the quantity will be increased, by repeating the evaporation, &c. If these crystals are dissolved in hot water, they will be freed from an oil, with which they are associated, and will recrystallize, on cooling. Being, then, dissolved in ether, and the resulting solution being evaporated to one-half, *adipic acid* ($C_6H_4O_3 + Aq$) will separate; and, when this is removed, and the residual liquor is farther evaporated, *lipic acid* ($C_5H_3O_4 + Aq$). If the adipic acid is boiled with alcohol, it will be obtained, in rounded grains; and the lipic acid, treated in the same way, in long plates. The nitric acid liquor still contains other substances, not yet examined.

131. On account of the low temperature, at which oleine congeals, it is well adapted for oiling watches, clocks, &c. Steam-engines, on the contrary, from the high heat to which they are exposed, require to be lubricated with substances, containing solid fats—which are even rendered still more effective, by the addition of wax.

132. The oleine of the drying oils, contains an oleic acid, that differs from what we have just examined; and, by absorbing oxygen, is converted into a kind of resinous varnish—carbonic acid being evolved. When acted upon by nitric acid, it produces, first, a resinous substance; and then, oxalic acid.

133. BUTTER contains—along with stearine, margarine, and oleine—*butyrine*, *caproine*, and *caprine*. The three first are separated, by melting the butter, and keeping it, for some days, at a temperature of 68° . The stearine, and margarine crystallize, and the oleine may be dissolved out from the residue, with alcohol.

134. When butter is saponified, and the soap is decomposed

by tartaric acid, the butyric, caproic, and capric acids remain dissolved : and may be easily removed from the stearic, margaric, and oleic—since, on distilling the liquor, they pass over, along with the water.

135. *Butyric acid* $C_4H_7O_2$ is most conveniently obtained, by dissolving one part sugar, in five of water; and causing the solution to ferment, by a temperature of between 90° and 100° , and the addition of cheese, or animal membrane. *Lactic* acid* ($C_6H_5O_5$) is first produced, one atom of cane sugar and one atom of water being changed, by catalysis [inorg. chem. 135], into two atoms of lactic acid. $C_{12}H_{19}O_9 + HO = 2C_6H_5O_5$. The lactic acid is separated, by adding pure carbonate of lime, occasionally, as long as it causes a precipitate. After a while, carbonic acid, and hydrogen, are evolved: and soluble butyrate of lime is produced from the lactate, butyric ($C_4H_7O_2$) being formed by decomposition of its lactic acid and water. $2C_6H_5O_5 + HO = C_4H_7O_2 + 4CO_2 + 4H$. The solution of butyrate of lime being distilled with hydrochloric acid, and fused chloride of calcium being added to the product, butyric acid separates, as an oily liquor; and may be purified, by redistillation. The process, by which this acid is obtained from sugar, is well calculated to illustrate, how easily fats are formed, in the animal system, from saccharine and other such substances. Butyric acid boils at above 212° . Distilled with lime, it gives *butyrone* (C_7H_7O), and *butyral* ($C_8H_8O_2$).

136. If the *caproic†* ($C_{12}H_{11}O_3$), and the *capric acid* ($C_{20}H_{19}O_3$)—obtained along with the butyric, from the saponified butter [134]—are distilled over, and neutralized with barytes, the three barytic salts may be separated, by repeated crystallization; and the acids, combined with an atom of water, may be procured from them. The caproic acid has the odour of perspiration: and boils at 396° : and its barytic salt crystallizes in long needles. The capric acid has the odour of a goat: it boils at 534° : and its barytic salt is insoluble, in cold water.

137. SPERMACETI, so called from an erroneous opinion as to its origin, is found—dissolved in spermaceti oil—in cavities of the skulls of different animals belonging to the whale species. After death, it separates from the oil by crystallization: and may be obtained, quite pure, by dissolving it in hot alcohol, until the latter takes up no more oil. It crystallizes from the alcoholic solution, on cooling; and is then termed *cetine*:‡ it is a combination of *cetylic acid* ($C_{32}H_{31}O_3$), and *ethal* ($C_{33}H_{34}O_2$). The cetylic acid is procured, by heating cetine, with fused potash and quicklime, to 350° : the potash changes the ethal into

* *Lac*, milk. *Lat.*; because one of the sources, whence it is obtained.

† *Capra*, a goat. *Lat.*

‡ *Cetus*, a whale. *Lat.*

cetylic acid, hydrogen being evolved, and water liberated; and the whole of the cetylic acid forms cetylate of potash, which, with chloride of barium, gives cetylate of barytes, and this, with a strong acid, cetylic acid. The latter may be distilled, unchanged, at 130° . It dissolves in alcohol, and ether.

138. Ethal, or hydrate of the oxide of *cetyle* ($C_{32}H_{33}$, or Ct) may be obtained, by fusing cetine with half its weight of potash, and digesting the saponified mass with dilute hydrochloric acid. The cetylic acid, and ethal, float on the surface. They may be separated, by adding lime—which forms cetylate of lime: and then boiling with alcohol—which dissolves the ethal, and precipitates it in the crystalline form, on cooling. Ethal melts at 119° : and passes off rapidly, in the form of vapour, at 250° . Cetylic acid, and ethal, have been considered, by some, as products of the decomposition of cetine, rather than its elements.

139. WAX.—It has not been ascertained, with certainty, whether this substance is merely collected by bees, or they are capable of producing it from their food. As the material of honeycomb, it is yellow: but it is bleached, by exposure to light in thin ribbons. When boiled with alcohol, it is separated into *cerine** ($C_{20}H_{40}O_2$), which dissolves, and is precipitated, by cooling, as a mass of fine needles: and *myracine* ($C_{20}H_{40}O$), which is insoluble. Cerine is less fusible than wax. It is saponified, by boiling with potash; and, with the process used to obtain ethal from spermaceti [138], affords *ceruine*—which, probably has the same constitution as myracine. The latter is not affected, by potash. The waxy substance, found on the surface of the sugar cane, is termed *cerosine* ($C_{46}H_{90}O$). It is not saponified, by potash.

140. SOAPS are salts of the fat acids.—Soap is mentioned by Pliny, who says it was invented by the Gauls, and was used to render their hair shining:—he does not seem to have known its detergent qualities.

Hard soaps are made with the fats, and the fat oils. *Soft soaps* with drying oils—sometimes, mixed with fish oils. The more stearate of potash or soda, the harder, and more soluble the soap: the more oleate, the less hard, and less soluble. The soaps of potash, are more soluble than those of soda:—oleate of potash dissolves in four parts water; but oleate of soda in not less than ten parts. Potash soaps are called, by the soap-boilers, “soft soaps,” even though dried artificially. They become a soft jelly, by exposure to the atmosphere: since stearate, margarate, and oleate of potash are deliquescent; which is not the case, with corresponding salts of soda. Soft soap is used in washing coarse linen, and in bleaching.

* *Cēra*, wax. *Lat.*

141. Hard soaps are separated from water, during their manufacture, by the addition of common salt. A saturated solution of the latter will not even wet muscular fibre, or soap, immersed in it: and no more will adhere to these substances, than if they had been dipped in mercury. When the solution of salt is not saturated, some water will unite with the soap. *Mottled* soap cannot be combined with more than a certain quantity of water; for, if this amount were exceeded, the soaps of copper, and iron—which cause the mottling—would, during manufacture, have subsided through the soap, on account of its greater fluidity. Since mottling is, ordinarily, a proof that soap is good, it is, in some cases, produced fraudulently. Exposure to the air, gives mottled soap a reddish tint, by oxidizing the iron.

142. Soft soaps are separated from the water, by a saturated alkaline solution. Soap of soda is often formed from a soap of potash, by the addition of common salt—chloride of potassium being produced.

143. The detergent qualities of soap depend on the fact, that the neutral stearates, margarates, and oleates of potash, and soda, are decomposed by cold, or hot water [118]—an alkali being set free. It is this alkali, which cleanses the clothes, by forming a soap with the unctuous matters which contaminate them—and which, being thus rendered soluble, are removed by washing. A caustic alkali, dissolved in water, would produce the same effect; but it would injure the texture of the linen, &c. The turbidity of “soap suds,” arises from the insoluble acid stearates, &c., held in solution.

144. Since earthy, and metallic soaps are, generally speaking, insoluble, the use of “hard” water, in washing, must be very injudicious:—for, not only is the soap decomposed and wasted, but the earthy and metallic soaps, which are formed, attach themselves to the clothes, and can scarcely, if at all, be removed. Carbonate of potash, or soda, “softens” the water, by separating any lime which may be present, before the soap is dissolved.

145. MANUFACTURE OF SOAP. The alkaline carbonate, whether obtained in kelp,* or [inorg. chem. 628] by decomposition of common salt, is first rendered caustic, by acting on it with lime [inorg. chem. 647]: and the resulting alkaline solution, termed a *ley*, is boiled with the oil, or fat, until the entire forms a viscid emulsion which may be drawn out into threads.—Undecomposed oil, or a deficiency of water, would cause turbidity. The soap is separated from the water, by the methods I have

* The “kelp,” or incinerated sea-weed, after having been used by the soap-boiler, still contains chloride of potassium, and is employed by the alum-maker, to change sulphate of iron into sulphate of potash. The latter, combined with the sulphate of alumina of burned clay-slate, forms *alum* $[(\text{SO}_3 + \text{KO}) + (3\text{SO}_3 + \text{Al}_2\text{O}_3)]$.

already described [141 and 142]: or it is boiled, until the concentration of the ley is such that the soap, being no longer soluble in it, floats on the surface. When the frothing ceases, the separation is known to be complete: and the "grain soap"—as it is called, in this state—may be ladled away into moulds. If it is to be manufactured into "white soap," it must be liquefied, with "ley," and the application of heat:—this will cause the impurities [141] to subside: and the soap will take up an additional quantity of water. Grain soap contains about thirty per cent. of that fluid: and white soap, almost twice as much. When the soap is to remain combined with an undue amount of water, evaporation is prevented, by immersion in brine.

146. *Resin Soap* is formed, by the union of resin with alkali—which is very easily effected. An alkaline carbonate will answer for the purpose: and, on adding an excess of the carbonate, or common salt, the soap separates, as a slimy brown mass which smells strongly of resin. It attracts large quantities of moisture from the atmosphere: and, by itself, is a "soft soap:"—but, along with a fatty soap, it forms a hard, and useful article.

147. The union of resin, with the alkalies, can scarcely be considered as saponification.—No glycerine is set free: and the acids of the resin are merely combined, at a boiling temperature, with the alkali, for which they have a yet stronger affinity than the fat acids.

148. The alkalies form saponaceous compounds, with hair, wool—and even flesh, fish, &c. Ammonia is evolved in these cases, and the fat acids are produced, more or less gelatine, &c., being mechanically mixed with the resulting soap. In this way, animal substances are completely dissolved by the caustic alkalies. In some instances, the bodies of workmen who, during the manufacture of soap, had unfortunately fallen into the pans, were found to have entirely disappeared—nothing being discovered of them afterwards, but the salts of their bones.

149. *RESIN*.—Ordinary "white resin," dissolved by oil of turpentine ($C_{30}H_{16}$), exists in different species of pine. When crude resin is distilled with water, the oil of turpentine passes off, in vapour: and resin—then termed *colophony*—remains behind. It is, in reality, a mixture of two resins—the pinic and silvic acids: they have different properties: but are isomeric, each being $C_{40}H_{30}O_4$.

Pinic acid* is obtained by acting on colophony, reduced to a fine powder, with alcohol, specific gravity 0.865—which dissolves the pinic, but not the silvic acid. The solution is then mixed, with an alcoholic solution of acetate of copper, as long as any thing is thrown down. The precipitate, which is pinate

* *Pinus*, a pine tree. *Lat.*

of copper, being dissolved in strong boiling alcohol, is decomposed by a little hydrochloric acid. The addition of water liberates the pinic acid, which is to be dried, by a gentle heat.

150. Pinic acid is colourless. It softens, at 149° , and melts, at 257° : dissolved in alcohol, it has an acid reaction. It expels carbonic acid from bases, forming alkaline salts which are soluble, and earthy or metallic salts many of which dissolve in spirit.

151. Long exposed to the atmosphere, it absorbs oxygen, and forms *oxypinic* acid ($C_{40}H_{30}O_8$). It is decomposed, by lime.

152. *Sylvic acid**—the residue after the pinic, has been separated [149] from colophony—is purified by dissolving it in two parts boiling alcohol, specific gravity 0.865. It separates, on cooling, and is still further purified, by repeated solution.

Sylvic acid melts at 212° . It is soluble in strong alcohol, and ether.

153. Either pinic, or sylvic acid, when kept melted for some time, becomes brown: and changes into colophonic acid:—a resin which is only sparingly dissolved by alcohol, and exists, to a small amount, in common resin.

154. There are a great variety of resins, differing somewhat in constitution, and properties. *Gum-resins*, are soluble in a mixture of water and alcohol.

155. CAOUTCHOUC $C_{8.72}H_{12.3}$, called, also, “gum elastic,” and “Indian rubber,” is obtained from the milky juice of several plants, which grow in hot countries.—A mould of clay is covered with successive coatings of the juice: and, when the covering is sufficiently thick, it is broken, and removed. Caoutchouc, while fresh, is of a yellowish white colour, but it grows dark by exposure to the air. It is remarkable for its tenacity and elasticity.—Threads of it are cut so fine, that 32,000 yards are made from one pound. They lose their elasticity by stretching and cold, but regain it if heated. Caoutchouc is quite rigid at 40° , melts at 240° , and at 600° , is resolved into a vapour which condenses by cold into *caoutchisine*—a liquid that dissolves caoutchouc and other substances, and is used in preparing certain varnishes. It burns with a bright flame:—and is used in Cayenne, instead of candles. It is soluble in ether, and rectified naphtha—obtained from wood, or coal-tar: also, in the oils, into which it is converted by distillation.—It is precipitated from ether, in the milky form, by alcohol. It dissolves, likewise, in essential oils: but, on account of the resin they contain, the caoutchouc remains viscid after they have evaporated. It is a non-conductor of electricity.

Substances rendered water proof, by caoutchouc, do not allow the escape of the insensible perspiration: and therefore

* *Sylva*, a wood. *Lat.*

are not healthful. When it is used for water-beds, the bed clothes are wetted by the perspiration, which has not the usual means of escape.

156. Caoutchouc, heated with sulphur, to 250° or 300° , combines with it, and forms "vulcanized Indian rubber:" a substance remarkable for its great, and permanent elasticity—at all temperatures under the vulcanizing point. It bears a much higher heat than ordinary Indian rubber, and is not affected by any known solvent.

157. There are several species of mineral caoutchouc; but they are less easily dissolved than what is derived from vegetables.

158. GUTTA PERCHA is the juice of a tree, which grows in Borneo—but whose history is not well known. It yields, by distillation, products analogous to those obtained from caoutchouc. Heated to 120° , it may be moulded with the fingers; and it preserves, with great accuracy, when cold, the figures, &c., stamped upon it, while in a soft state. It is sometimes used for bands, &c., in machinery: and for the soles of shoes, &c. It may be joined easily, if the parts that are to be united, are kept *perfectly* clean, and are not over-heated.

159. STARCH.—The composition of this substance, whatever may have been its source is $C_{12}H_{10}O_9 + 2HO$. It is found abundantly, in wheat, potatoes, &c.: and is imbedded in the cellular tissue of the plant, in the form of small white grains, of different sizes—those of a potato, the largest, being the $\frac{1}{250}$ th of an inch, and those of arrow root, which are among the smallest, the $\frac{1}{800}$ th of an inch, in diameter. These grains are, sometimes, globular: at others, ovidal: and, occasionally, even in the same plant, irregular.

160. Starch may be obtained, by scraping the potato into cold water: then pouring off the milky liquor, and allowing it to settle. The starch will fall down, and may be purified, by washing it again with water, and separating it, as before. The grains of starch consist of concentric layers, increasing in density from the centre. They are insoluble in cold, but—except the outer layers—are soluble in hot water. If the solution is dried at a gentle heat, and the residue is dissolved in cold water, the outer layers may be removed by filtration: after which, the solution will be quite clear. Dried at the temperature of 140° , a solution of starch forms a transparent mass; at 212° , it loses an atom of its water, and becomes $C_{12}H_{10}O_9 + HO$; heated to 240° , it softens and becomes brown; heated till it smokes, it forms "British gum"—a substance quite insoluble in cold water. Starch gives with iodine a blue [inorg. chem. 363]: and with bromine, a yellow [inorg. chem. 367] precipitate.

161. When a potato is frozen, the cells which contain the

starch, are burst; and the juice of the epidermis flowing into the interstices, renders it not only unwholesome, but so unpalatable, that neither man nor beast will eat it.—If the potatoes are dried, immediately after being thawed, such an inconvenience will not follow; but, on the contrary, being deprived of their vitality, they will keep for an indefinite period. This method of preserving potatoes has been long used by the Peruvians. Frozen potatoes will afford very little starch; because the cells, having been separated from each other by the frost, are not torn open, nor are their contents disengaged, by rasping.

162. When starch is obtained from wheat, the latter is made to ferment, and become sour—that the gluten, which would attach itself to the starch, may be removed.

163. LICHENINE is a species of starch. It is found in many lichens, particularly “Iceland moss,” and “Carrigeen.” It does not occur in grains, but in solution; and it gives, with iodine, a greenish brown precipitate.

164. GUM.— $C_{12}H_{11}O_{11}$. It is a well-known substance; and is obtained from the juices of many plants. It is of various kinds;—that which is termed *arabine* is found in commerce, as “gum arabic,” and “gum senegal.” It is soluble in water, forming a liquid, called “mucilage:” and is precipitated, from its aqueous solution, by alcohol. It forms, with nitric acid, first *mucic acid* ($C_{12}H_8O_{14}$)—by absorbing six atoms of oxygen: and then oxalic acid. It exerts a rotary power [opt. 251] on a polarized ray of light: and it gives a precipitate, with a solution of soluble glass [inorg. chem. 411].

165. *Tragacanthine*, or “vegetable mucus,” exists in the cherry tree, &c.—but, in its purest form, in “gum tragacanth.” It gives no precipitate with soluble glass.

166. *Dextrine*.—An artificial gum, may be obtained, by keeping five parts starch, one part oil of vitriol, and fifteen parts water, for some time, at a temperature of 200° .—The starch disappears: and the resulting dextrine may be separated from the sulphuric acid, by carbonate of barytes.

Unlike ordinary gum, dextrine exercises a *dextral* [opt. 250] rotary power, on a polarized ray.

167. SUGAR.—Under this name are comprehended all substances, capable of the vinous fermentation:—or in other words, of being resolved, by a particular species of decomposition, into alcohol, and carbonic acid. Although gum has the same composition as cane sugar, it does not possess this property; nor is it acted on, by fermenting substances.

168. *Cane sugar*:— $C_{12}H_{20}O_{10} + 2Aq$, when crystallized. It is found in the sugar cane, beet root, carrot, turnip, potato, &c.: and, in the nectaries of most flowers. To obtain it, the juices from

which it is derived are clarified, at the temperature of 150° ; with lime—which coagulates the vegetable albumen, and checks the fermentation, into which they run with great rapidity. They are then evaporated, at as low a temperature as possible, and placed to cool, in vessels having apertures which are temporarily closed. When the syrup has congealed into a granular mass, the “molasses,” or liquid uncrystallizable part, runs off: and “Muscovado,” or raw sugar, remains. To purify it still further, it is redissolved, and the solution being evaporated, it is poured into cones of unglazed earthenware, which are placed on their vertices—the apertures that are in the latter, being stopped with plugs: while cooling, the sugar is stirred about, to diminish the size of the crystals. Finally, the plugs are removed, that the fluid which is still present may run off—The result is “loaf sugar.” If the saccharine solution is left in a warm place to crystallize, “sugar candy” is produced. A strong solution of sugar, kept, for some time near its boiling point, is gradually changed into uncrystallizable sugar.—To prevent the waste, which might arise from this cause, the evaporation [heat 111] is sometimes carried on, *in vacuo*.

169. Sugar, when quite pure, is colourless. Its crystals are four sided, or irregular six sided prisms, acuminate on two surfaces. Pieces of sugar rubbed together in the dark, become highly phosphorescent. Its specific gravity is 1.6065. At 350° , it melts into a colourless liquid which, when cooled suddenly, forms “barley sugar.” At 630° it gives off water, and becomes *caramel* ($C_{12}H_9O_9$) a dark brown shining porous substance, soluble in water, but insoluble in alcohol; and capable of combining with bases. At a higher temperature, it is decomposed into combustible gases, charcoal, &c. It dissolves abundantly in hot, and in one-third of its weight of cold water. A saturated solution—called a “syrup”—is, by the presence of a small quantity of oxalic, citric, or malic acid, rendered incapable of forming crystals: and the organic acids, cannot always be removed, by alkalies. Sugar acts as a weak acid, and unites with oxides. It forms, with common salt, a compound, of which the constitution is $2C_{12}H_{10}O_{10} + NaCl$.

170. Cane sugar is changed, by dilute sulphuric, or hydrochloric acid, into grape sugar ($C_{12}H_{22}O_{11} + 3Ag$); but, by these acids, in a concentrated form, into a brown substance, consisting of *sacculmine* ($C_{40}H_{16}O_{14}$), and *sacculmic acid* ($C_{40}H_{14}O_{12}$).—They are insoluble in water, and alcohol: and are easily separated, on account of the sacculmic acid being dissolved by alkalies, and precipitated from solution, as a brown powder, by acids. Sacculmic acid is converted by boiling, for a long time, with water, into sacculmine.

171. When sugar is boiled, for a considerable time, with a

stronger acid, *saccaro-humine* ($C_{40}H_{15}O_{15}$), and *saccaro-humic acid* ($C_{40}H_{12}O_{12}$) are the results. They are insoluble in water, and alcohol: and may be separated, by dissolving the saccharo-humic acid in an alkali. Unlike sacculmine, and sacculmic acid, neither saccharo-humine, nor saccharo-humic acid can be produced, without access of air.

Sugar, heated with lime, forms *metacetone* (C_6H_5O) a volatile liquid.

172. If, in the process, for making oxalic acid [42], dilute is used, instead of concentrated nitric acid, the result is a liquor which gives, with carbonate of lime, a neutral solution. When this is decomposed with acetate of lead, a white precipitate is formed. If the latter is acted upon, with sulphuretted hydrogen, *saccharic acid* ($C_{12}H_5O_{11}$), is set free. It is penta-basic, and may be obtained in the crystalline form, by evaporation, and cooling.

173. *Grape sugar*:— $C_{12}H_{11}O_{11} + 3Aq$ when crystallized. This is called, also, “glucose.”* It is identical with sugar of diabetes, with sugar of starch, of fruit, honey, &c.; and is the product of germination. Sugar is produced when hay becomes heated, from not having been thoroughly dried:—and the sweetness of old hay is probably due to this change having occurred to a slight extent. It can be made from cane sugar, by boiling, for a sufficiently long time, with sulphuric acid: and, from starch, by fermentation. It is produced, by acting upon linen with its own weight of oil of vitriol—without allowing the mixture to become heated. The result is a uniform, viscid mass, which is to be diluted with water, and boiled for some time: after which, the sulphuric acid may be removed, with chalk; and the sugar, purified by crystallization. It is very conveniently obtained, from raisins, or honey, by digesting with cold strong alcohol—to remove the uncrystallizable sugar; then expressing the residue, dissolving it in water, and neutralizing the solution with chalk: after which, the liquor may be clarified with white of egg, and evaporated until crystals are formed.

174. Grape sugar is less soluble, and less sweet, than cane sugar. It is very soluble in cold alcohol; but, when dissolved in hot alcohol, it combines with the latter, and precipitates, almost entirely in granular crystals. Its specific gravity is 1.386. It melts at 212° ; and, at 286° , changes into caramel [169]. Strong mineral acids, which hardly act upon cane sugar, decompose grape sugar. Oil of vitriol dissolves it, and produces *sulpho-saccharic acid*, which, as sulpho-saccharate of lead ($2C_{12}H_{11}O_{11} + SO_3 + 4PbO$) is not precipitated, by barytes.

175. Alkalies, which form compounds with cane sugar, de-

* *Glukūs*, sweet. Gr.

compose grape sugar. Lime, which affects cane sugar but slowly, forms very rapidly, with grape sugar, *glucic acid* ($C_{12}H_8O_8$)—in its dry state, isomeric with *lignine*. When a solution of caustic potash is boiled with grape sugar, the resulting *glucic acid* is decomposed; and a brown liquor is formed, which, with hydrochloric acid, affords *melassic* acid* ($C_{24}H_{12}O_{10}$), in the form of a black, flocculent precipitate. Cane sugar, rotates the plane of polarization [opt. 250] to the left: but grape sugar, almost always, to the right.

176. LACTINE† or “sugar of milk:”— $C_{24}H_{19}O_{19} + 5Ag$, when crystallized. It has been found, as yet, only in the milk of the mammalia; and may be obtained, by evaporating whey to a pellicle.—On setting it aside to cool, the sugar crystallizes: and the crystals may be purified, with animal charcoal, and repeated crystallization. They are white, semitransparent, hard, and crackle under the teeth. Their specific gravity is 1.543. They are insoluble in alcohol, or ether: but dissolve, in six parts of cold, and in two and a half of boiling water: and their solubility is increased, by the presence of an acid, or an alkali.—Their concentrated solution does not form a syrup [169]. They are but slightly sweet; and rather less so than their solution. Heated to 290° , they give off two atoms of water; at 300° , they fuse, and abandon three atoms more. Sugar of milk is changed into grape sugar, by digestion with dilute sulphuric acid. Like gum, and unlike the other sugars [164], it forms *mucic acid*, when acted upon with nitric acid.

177. The following, according to Liebig, are the constituents of starch, gum, and the sugars which I have noticed:—

Starch	= ($C_{12} + 10HO$)
Gum	= ($C_{12} + 10HO$) + HO
Cane sugar	= ($C_{12} + 10HO$) + HO
Sugar of milk	= ($C_{12} + 10HO$) + $2HO$
Grape sugar	= ($C_{12} + 10HO$) + $4HO$

178. MANNITE:— $C_6H_7O_6$. It is the sweet principle of “manna;” and—though it does not form alcohol [167]—is closely connected with the sugars. It is generated, along with other substances, when beet-root, or carrot, is kept for some time at the temperature of 100° —what has been called the *mucous fermentation* being produced. This species of fermentation, which sometimes causes loss, during the manufacture of sugar, may be produced by contact with “mucous membrane.”

179. DIASTASE‡ is that principle, in malt, which converts starch into sugar. It contains nitrogen; but its constitution has not yet been determined.

* *Melas*, black. *Gr.* † *Lac*, milk. *Lat.* ‡ *Diastēmi*, I separate. *Gr.*

It may be obtained, by moistening malt of the best kind, with water : then pressing it, and mixing the juice with a little alcohol—to separate the albumen, &c. : lastly, filtering, and evaporating to dryness. The residue, a white gummy mass, is impure diastase.

180. It is tasteless, and without colour. It is soluble in water, and weak alcohol : but insoluble in absolute alcohol. If the temperature does not exceed 158° , one part diastase will, in a few hours, change 2,000 parts starch, into sugar ; and, as the change proceeds, will itself disappear. It is precipitated by infusion of galls, and by most metallic salts. The presence of diastase during fermentation, changes the starch of the seed, into sugar.

181. THE VINOUS FERMENTATION.—Fermentation is divided into the *saccharine*,* in which starch is changed into sugar ; the *vinous*,† in which sugar is changed into alcohol ; the *acetous*,‡ in which the alcohol is changed into acetic acid ; the *viscous*, or “mucilaginous,”§ in which gum is one of the products—and which occurs, when malt liquor is fermented without yeast ; and the *putrefactive*, in which the whole substance undergoes decomposition—the results being a number of new products, accompanied by a disagreeable smell. Other processes are, occasionally, termed fermentation:—thus the *lactic*,|| in which sugar is changed into lactic acid ; and the *panary*,¶ which occurs during the fermentation of dough, but which is resolvable into one of the others—generally the vinous.

182. *The vinous fermentation* takes place, when saccharine solutions, at a proper temperature, are placed in contact with substances in a state of decomposition—*yeast*, for instance. Blood, white of eggs, glue, flesh, &c., if they have begun to putrefy, would also cause sugar to ferment. During fermentation new compounds are produced ; and the liquor will afterwards be found to contain *alcohol*.

183. Substances which have no nitrogen, are of themselves incapable of the vinous fermentation ; but they are made to ferment, by the addition of a substance containing it. Sometimes the liquid, to be fermented, contains the *ferment*, or exciting body, within itself:—thus, the juice of the grape. The nitrogenized substances of the fermenting liquor are precipitated, as “ferment:” and may be used to cause, or to commence, the fermentation of other liquors.

184. Contact with the atmosphere is necessary to begin, but not to continue, the vinous fermentation.—The skin of fruits, while entire, prevents fermentation, by excluding the air.

* *Saccharum*, sugar. *Lat.*

† *Acetum*, vinegar. *Lat.*

|| *Lac*, milk. *Lat.*

† *Vinum*, wine. *Lat.*

§ On account of the formation of *mucus*.

¶ *Panis*, bread. *Lat.*

During the formation of alcohol, one atom of grape sugar ($C_{12}H_{11}O_{11} + HO$, when dried at 212°) produces four atoms of carbonic acid, and two of alcohol ($C_4H_6O_2$). $(C_{12}H_{11}O_{11} + HO) = 4CO_2 + 2C_4H_6O_2$.—Every kind of sugar, before fermenting, is changed into grape sugar. The various species of sugar do not all ferment with equal facility. Milk requires a strong ferment, and an acid, to change sugar of milk into grape sugar:—hence, it does not ferment, until it has become sour, and coagulated.

185. BREWING.—The method of producing fermented liquors, appears to have been known from the earliest times: but distillation, not until a comparatively recent period. We are told, by Herodotus, that the Egyptians made a wine from barley, having no grapes. And we are informed, by Tacitus, that beer was the favourite drink of the ancient Germans:—as it still continues to be of the modern. The first and most important step preparatory to brewing, is “malting” the corn—which, by means of incipient germination [173], changes the starch into sugar. For this purpose, the grain is steeped in soft cold water, for about sixty hours: after which, the water being drained off, its temperature rises: and it begins to grow—but the growth is stopped, by the heat of a kiln. All the starch has not been transformed into sugar:—if it were, the entire grain, except the husk, would now be perfectly soluble. Too high a temperature, in the kiln, would injure the saccharine matter, which—at least when separated from the malt—is decomposed below the boiling point of water.

186. After the malt has been ground, it is “mashed” with water, not sufficiently hot to form the starch which remains into paste.—And, as the undecomposed starch is gradually changed, by its own gluten, into sugar, water of gradually increased temperature, is added. Mashing, renders the solution of the saccharine matter complete. The clear liquor, or “worts,” is next strained off: and is immediately transmitted to the coppers—to be partially boiled away, and further clarified. Boiling, with excess of oxygen, would throw down vegetable matter, as an insoluble precipitate—which would be a source of waste.

187. Hops are next added.—They were first imported from the Netherlands, about the year 1524. Most of their useful properties reside in a fine yellow powder, which may be separated from them.—They contain a volatile oil, also, which gives an agreeable aroma to the beer: but most of it is driven off, by the temperature at which the wort is boiled. The hop changes the flavour of the beer, adds to its narcotic qualities, and prevents acetous fermentation.

188. After the bitter principle has been extracted from the

hops, the liquor is strained into a vessel called a "cooler."—It must be cooled rapidly, to prevent acidity. When it is cool, it is transferred to the "fermenting tun," and yeast is mixed with it. Carbonic acid now escapes, in large quantities, through the viscid froth which forms on the surface, and which is ultimately removed.

189. To clear the liquor from the yeast which, if allowed to remain, would produce acidity, and to check the vinous fermentation, it is poured into lesser vessels:—the small quantity of saccharine matter, which is thus left undecomposed, afterwards generates carbonic acid, in the beer, &c. The liquor may be still further cleared, by "fining:" which is effected, by adding isinglass dissolved in sour beer.—Becoming entangled in the particles which produced turbidity, it falls along with them, to the bottom of the vessel. Other substances might be used, for the same purpose.

190. The presence of alcohol, in beer, &c., may be shown, by means of dry carbonate of potash—which is insoluble in alcohol. It will be dissolved by the water, contained in the liquor, and the alcohol will float over the solution.

191. DISTILLATION.—The changes which occur, during the process of brewing, have produced alcohol; but its formation is not the sole object of the brewer:—it would not even suit his purpose to generate so much of it, as he might have done. The ends, proposed by the distiller, are quite of another kind. He also produces alcohol, by fermentation, but he *separates* it from the fermented liquor. Hence his mode of obtaining it must be somewhat different from that which I have just described—though founded on precisely the same principles.

192. As the alcohol is to be removed from the substances, with which it is associated, and the qualities of the residue are of but little consequence to him, it is not necessary for the distiller to provide against acetification. Also, in distillation, as much alcohol as possible is formed. The ingredients used, are not, necessarily, grain; and, if grain, it is not required to be of the same kind, nor that the entire—or indeed any of it—should be malted: it is even said that malting diminishes the amount of alcohol.—The large quantities of yeast, which are employed, produce a very energetic fermentation, which is quite sufficient, of itself, both to form, and separate the sugar. The fermented liquor is, in distillation, termed "wash."

193. The wash is transferred to the *still*: a boiler so contrived, that the vapour, which rises from it, is conveyed, by a bent tube called the *worm*, through cold water: and is thus condensed into a liquid. Those fluids which boil at a lower temperature than water—such as alcohol, and the essential oils—rise first, by evaporation; but, since bodies communicate to

others the capability of being evaporated, at low temperatures [inorg. chem. 338], they carry along with them a portion of the water, in the form of steam. The mixture of alcohol and water, which condenses in the worm, is transmitted to a suitable vessel. A second, third, and fourth distillation, will strengthen the alcohol, by removing successive portions of the water, with which it is diluted: but a fifth, is productive of no further effect. The vapour of water condenses, chiefly, in the first, or hotter parts of the worm:—contrivances have, therefore, been employed, for conveying it back to the still, instead of allowing it to pass into the receiver. The first distillation gives what is, technically, termed “singlings;” the second, at the commencement, “first shot,” and afterwards “whiskey;” subsequent distillations “rectify,” by removing water, and a very disagreeable essential oil. The latter causes the bad flavour of inferior spirits: and is often present in such quantity as to produce turbidity, when the alcohol is rendered so dilute, by the addition of water, as to be no longer capable of holding it in solution.

194. ALCOHOL:— $C_4H_6O_2$, when anhydrous. It may be considered, as *etherine* (C_4H_4), combined with two atoms of water. Spirits may be obtained, from any of the vast number of substances, which contain starch, or sugar; but their qualities are different—particularly their flavours, which are due to the essential oils, they hold in solution, and which may be separated from them. The residue, after this oil, and every other impurity, has been removed, is termed *alcohol*; and, from whatever source it may have been derived, it is always the same.

195. According to Brande, ordinary spirits, such as brandy, whiskey, &c., contain from 40 to 50 per cent. and upwards, alcohol. Strong wines, such as port, or sherry, from 19 to 25 per cent. The wines of France and Germany, about 12 per cent. Strong ale, about 10 per cent. The specific gravity of *proof spirit*—which contains 48 per cent. alcohol—is about 0.920. The most highly rectified spirit, contains only 90 per cent. and its specific gravity is between 0.835 and 0.840, at a temperature of 60°. This is the greatest strength, attainable, by simple distillation. If a purer alcohol is required, some substance—such as pearl-ash, &c.—that has an affinity for water, must be distilled, along with it, from a water bath:—part of the pearl-ash will, however, pass over, also [inorg. chem. 338].

196. If it is not necessary that it should contain more than 98 per cent. absolute alcohol, it may be obtained, of that strength, by tying it up in a bladder. The water, which exceeds 2 per cent. will pass through the membrane, and will be evaporated from its surface [inorg. chem. 212]:—but some of the alcohol, also, will pass off from the empty portion of the bladder.

197. *Absolute alcohol*, or that which is perfectly anhydrous,

may be obtained, by saturating fused chloride of calcium with the most highly rectified spirit: and distilling from a water bath. Or, by pouring very strong alcohol upon quick-lime.—The water of the alcohol will slake the latter; and so much heat will be produced, as will cause absolute alcohol to pass over, in vapour.

198. Absolute alcohol is a clear, and colourless fluid. Its specific gravity at 60° , is 0.7947. It is a non-conductor of electricity. It boils at 168° : and has never yet been frozen.—Since its boiling point is the same as that of alcohol containing 6 per cent. water, the first part of what is obtained, by distillation, from fused chloride of calcium [197] should be rejected, as hydrated. Alcohol has a strong affinity for water:—which makes it be destructive to life, on account of its depriving the organs of the water, required by them. The same reason causes it even when dilute, to produce a burning sensation, in the mouth and throat. When it combines with water, condensation occurs, and heat is evolved.—If one atom of alcohol is added to six of water, the bulk of the mixture will be to that of its constituents, as 100 is to 103.735.

199. Snow, and absolute alcohol constitute a very effective freezing mixture [heat 114]:—the alcohol, on account of its affinity for water, melts the snow with great rapidity.

200. If alcohol is rendered impure, by the presence of an essential oil, it will be discoloured by colourless oil of vitriol; or, by nitrate of silver and exposure to the sun's rays. It should produce no change, in test paper; and, when evaporated, should leave no stain.

201. Alcohol is decomposed, by oxacids, into water, and the oxide of *ethyle* (C_4H_5O , or *ether*)—which generally remains in combination with the acid. Thus, nitric acid (containing no nitrous acid) and alcohol, form nitrate of the oxide of ethyle, and water. $NO_5 + C_4H_6O_2 = (NO_5 + C_4H_5O) + HO$. Hydracids decompose the oxide of ethyle, and, at the same time, themselves suffer decomposition. Thus hydrochloric acid (in the nascent state) and alcohol, form chloride of ethyle, and water. $HCl + C_4H_5O_2 = (CH_3Cl) + 2HO$.

202. An alcohol, taken in the more extended sense, is considered to be “a substance, which may be represented by two atoms of water and a hydrocarbon isomeric with olefant gas; which, being deprived of an atom of water, forms an ether; and which, the two atoms of water being replaced by four atoms of oxygen, forms an hydrated acid.” These conditions apply to others, besides the ordinary or vinous, alcohol. Thus—

	Wood alcohol.	Vinous alcohol.	Oil of potato spirit.	Ethal.
Alcohol,	$C_2H_2 + 2HO$	$C_4H_4 + 2HO$	$C_{10}H_{10} + 2HO$	$C_{32}H_{32} + 2HO$
Ether,	$C_2H_2 + HO$	$C_4H_4 + HO$	$C_{10}H_{10} + HO$	$C_{32}H_{32} + HO$
Acid,	$C_2H_2 + O_4$	$C_4H_4 + O_4$	$C_{10}H_{10} + O_4$	$C_{32}H_{32} + O_4$

Only vinous alcohol, and the substances connected with it, are of sufficient importance to require notice, here.

203. ETHER.—An ether is a very volatile fluid, produced by the distillation of alcohol with an acid. I shall confine myself to *sulphuric ether* (C_4H_5O) called, more commonly, *ether*. It may be obtained, by adding potassium to absolute alcohol:—potash, and ether, will be formed, and hydrogen will be evolved. It is, however, very conveniently procured, by mixing equal weights of rectified spirit and oil of vitriol. Any considerable rise of temperature must be avoided: distillation ought to be effected, not in an open fire, but a sand bath:—and the greatest care should be taken, throughout the whole process, on account of the inflammable nature of both alcohol, and ether. A mixture of ether, alcohol, and water will pass over. The first product is a fragrant spirit: then, as soon as the liquid boils, ether; next, a light yellow oil, called “sweet oil of wine;” finally, sulphurous acid, and olefiant gas—after which, the mixture becomes thick and black, and froths up. It is very economical to add the alcohol by degrees—if possible in a continuous stream. This may be done, by means of a safety funnel [inorg. chem. 86]. The reactions I have mentioned, are then avoided: and the same oil of vitriol, will decompose twice its weight of rectified spirit. Ether continues to be set free, until the sulphuric acid becomes so weak as to be quite ineffective—that is, until it is $SO_3 + 4HO$, which, unless at a high temperature, is incapable of decomposing alcohol.

204. This process is not so simple, as might be imagined. The sulphate of ether ($SO_3 + C_4H_5O$) which is first produced, combining with another atom oil of vitriol, forms bisulphate [$(SO_3C_4H_5O) + (SO_3 + HO)$], or *sulphovinic acid*—which affords a soluble salt, with barytes, or oxide of lead. It is then decomposed by the excess of water present:—and in this point, resemble the sesquioxides of iron, bismuth, and antimony, which, if combined with sulphuric acid, are set free by water, particularly when it is at a boiling temperature.

205. If the heat is kept moderate, during the process, scarcely any water passes over along with the ether. The latter is rendered perfectly pure, by rectification with dry carbonate of potash, from a water bath.

206. Ether is a colourless liquid, of a penetrating, but agreeable smell, and a pungent taste. Its specific gravity at 60° is 0.720. It is a non-conductor of electricity. It crystallizes at -47° : and boils, in the atmosphere, at 96° , but in vacuo at 20° . It evaporates, at ordinary temperatures, with great rapidity, causing considerable cold [heat 90]. Its vapour, like that of alcohol, when mixed with common air, is explosive. It dissolves, in ten times its weight of water:—but alcohol is slowly produced, by the ether combining with that fluid. This combination

takes place rapidly, if the ether is in the nascent state:—as, when the acid salts of ethyle are heated with water; or, when its neutral, or haloid, salts are decomposed, by being heated with hydrated alkalies; or when, during the vinous fermentation, sugar is decomposed.

207. If a small quantity of ether is thrown into a bottle of chlorine, a white vapour is produced, with explosion and flame. Ether dissolves iodine, and bromine, abundantly; but they ultimately act upon it. If the salts, which ether forms with acids, have an acid reaction, they are termed *acids*—thus, phosphovinic acid ($\text{PO}_5 + \text{C}_4\text{H}_5\text{O} + 2\text{HO}$); if they are neutral, *compound ethers*—thus, oxalic ether ($\text{C}_2\text{O}_3 + \text{C}_4\text{H}_5\text{O}$).

208. Ether has been considered, by some, to be a combination of olefiant gas, and water—or its elements; and by others, the oxide of an hypothetical radical *ethyle* (C_4H_5 , or *Ae*). This difference of opinion is similar to that which exists, regarding the nature of ammonia:—the question being, whether the oxygen and hydrogen present in each, actually constitute water, or form an integral part of a base. If *acetylene* (C_4H_3 , or *Ac*) is supposed to be the radical of ether, and *amidogene* (NH_2 , or *Ad*)—as proposed by Sir R. Kane—that of ammonia, their compounds will agree in a very remarkable manner—

Acetylene,	Ac	Amidogene,	Ad
Olefiant gas,	AcH	Ammonia,	AdH
Ethyle,	AcH ₂	Ammonium,	AdH ₂
Ether,	AcH ₂ O	Oxide of ammonium,	AdH ₂ O
Chloride of ethyle	AcH ₂ Cl	Sal-ammoniac,	AdH ₂ Cl

209. The following is a tabular view of the most interesting substances, connected with alcohol—

Olefiant gas, or elayle,	C_2H_2
Etherol, etherine, or light oil of wine,	C_4H_4
Ethyle,	<i>Ae</i> , or C_4H_5
Oxide of ethyle, or ether,	<i>AeO</i>
Oxide of ethyle and water, or alcohol,	<i>AeO</i> + <i>HO</i>
Chloride of ethyle, or hydrochloric ether,	<i>AeCl</i>
Iodide of ethyle, or hydriodic ether,	<i>AeI</i>
Bromide of ethyle, or hydrobromic ether,	<i>AeBr</i>
Sulphuret of ethyle, or hydrosulphuric ether,	<i>AeS</i>
Bisulphuret of ethyle, or thialol,	<i>AeS</i> ₂
Sulphur alcohol, or mercaptan,	<i>AeS</i> + <i>HS</i>
Cyanide of ethyle, or hydrocyanic ether,	<i>AeCy</i>
Sulphovinic acid,	$[(\text{SO}_3 + \text{AeO}) + (\text{SO}_3 + \text{HO})]$
Phosphovinic acid,	$(\text{PO}_5 + \text{AeO}) + 2\text{HO}$
Arseniovinic acid,	$(\text{AsO}_5 + \text{AeO}) + 2\text{HO}$
Carbonate of the oxide of ethyle, or carbonic ether,	$\text{CO}_2 + \text{AeO}$
Chlor-oxy-carbonic ether,	$[(\text{CO}_2 + \text{AeO}) + (\text{COCl})]$

Carbovinic acid,	$[(\text{CO}_2 + \text{AeO}) + (\text{CO}_2 + \text{HO})]$
Sulphocarbonic ether, or hydroxanthic acid,	$[(\text{CS}_2 + \text{AeO}) + (\text{CS}_2 + \text{HO})]$
Oxalate of oxide of ethyle, or oxalic ether,	$\text{C}_2\text{O}_3 + \text{AeO}$
Oxalovinic ether,	$[(\text{C}_2\text{O}_3 + \text{AeO}) + (\text{C}_2\text{O}_3 + \text{HO})]$
Oxamethan, or oxalate of the oxide of ethyle and oxamide,	$[(\text{C}_2\text{O}_3 + \text{AeO}) + (\text{C}_2\text{O}_2 + \text{Ad})]$
Acetate of the oxide of ethyle, or acetic ether,	$\bar{\text{A}} + \text{AeO}$

210. MANUFACTURE OF BREAD. The materials of which bread is made would, in the raw state, be difficult of digestion. Simply exposing them, after being made into flour and kneaded with water so as to form dough, to the application of heat, produces such a change as makes the result, not only more easily masticated, but also far more wholesome. Consequently, bread of some kind, has been used from the earliest times. But it is rendered still more digestible, if subjected, before baking, to an incipient fermentation: being rendered lighter, on account of the air cells, which are caused by the disengagement of elastic fluids. The latter are produced, either by leaven, or by yeast. The former method which, as we learn from Scripture, is of high antiquity, consists in causing the fermentation of a large mass, by the addition to it of a small quantity of *leaven*—or dough already in a state of fermentation. If, instead of employing “leaven,” the whole were allowed to ferment of itself, one part might be sour or mouldy, while another would be still unaffected. The use of yeast, as a substitute for leaven is of modern date. The bread made by it is, to our taste at least, more palatable; but the fermentations, produced by leaven, and by yeast are, most probably, the same. There can be no doubt that, when yeast is applied, the vinous fermentation results; and spirit has actually been obtained, during the process of baking—though not in sufficient quantity, to render it worth the trouble of preserving. It is almost certain, that the vinous fermentation is produced by leaven, also: but the bread is more or less sour, from the presence of an acid.

211. Although it is very desirable that bread should be light, it is not always possible to obtain yeast:—hence, what is called “soda bread” has been, of late, very much used. Its lightness is due to carbonic acid, disengaged from bicarbonate of soda. The latter is mixed with the flour, and is decomposed by an acid—sometimes, by that contained in sour milk, but more conveniently, by dilute hydrochloric acid. This kind of bread has not the advantage of its constituents being even slightly broken up, by incipient fermentation;

nevertheless, it is said to have properties, which render it at least as wholesome as that which is made with yeast.

212. That no accident may occur from neglect, &c., it is proper to keep the hydrochloric acid in a very dilute state. And, since just so much of it should be added, as will disengage the carbonic acid, it ought, as soon as prepared, to be tested with a small and known quantity of the bicarbonate. The amount of dilute acid, required to liberate all the gas, may be ascertained, by adding it gradually until effervescence is no longer produced; and what is necessary for the bicarbonate, required by any quantity of bread, may be easily calculated, from the result.—The same dilute acid, will evidently require to be tested, but once: and, as the bicarbonate of soda will be changed into common salt, less of that substance is to be added to the dough. Half an ounce avoirdupoise bicarbonate of soda, $4\frac{3}{4}$ fluid drachms hydrochloric acid specific gravity 1.16, $\frac{1}{4}$ oz. common salt, and two imperial pints of cold water, have been found the proper quantities for 4 lbs. of flour. The soda should be well mixed with the flour, the acid and common salt with the water, and then all the ingredients together.—If the bread is kneaded too much, it will be heavy.

213. The mistake made, as far as nutrition is concerned, by preferring the more palatable species of bread, may be conceived from what is stated by Professor Johnston: that—

	lbs.
1,000 lbs. of whole grain contribute to the fat . . .	38
„ fine flour „ „ . . .	20
„ bran „ „ . . .	60
1,000 lbs. of whole grain contribute to the matter of the muscles	156
„ fine flour „ „ „	130
1,000 lbs. of whole grain contribute to the formation of bone and saline matter . . .	170
„ fine flour „ „ „ „ „	60
„ bran „ „ „ „ „	700

Fortunately for themselves, workpeople are deprived of the finer kinds of bread.

214. LIGNINE:— $C_{12}H_8O_8$.—It is formed from starch by [22] three atoms of water being removed. It constitutes the tubes, and cells, of vegetable tissues: and may be obtained, by successive and repeated treatment of wood, with dilute acids, alkalies, water, and alcohol—to take away all the soluble substances. It is quite white, when pure, and remains undecomposed for a long time, if kept either quite dry, or under water—which protects it from oxygen. It is changed by hot nitric acid, into oxalic acid: and, by sulphuric acid, first into gum, then into sugar. Sawdust, treated for some hours with a warm solution of potash, gives a mixture of starch and lignine,

which, with iodine, will strike a blue colour. The bleaching of linen, frees the lignine from resinous and other matters, associated with it. As flax, when dressed, consists almost entirely of lignine, if what has been separated from it is returned to the soil, it will no longer be an exhausting crop.

215. GUN COTTON.—Braconnot observed, in 1833, that, when starch was heated in strong nitric acid, until complete solution took place, if the solution was poured into a large quantity of cold water, a white pulverulent amorphous mass gradually subsided, and, on being dried, was highly combustible—burning without any residue. This substance was called “Xylodine:”* and consists, according to Pettenkofer, of $C_{36.76}H_{4.70}O_{53.80}N_{5.65}$; but, according to others, of $C_{12}H_8O_{18}N_2$. Pelouze in 1838, repeated the experiments of Braconnot, and ascertained that paper, linen, cotton and other ligneous substances, without altering their appearance, gave apparently the same body if, being submitted for a few moments to the action of nitric acid, specific gravity 1.5, they were well washed with water, and dried: and he suggested its application, as a substitute for gunpowder. But he, and other chemists, have since found, that what are obtained from starch, and from woody fibre, are not identical. The latter has been called *pyroxyline*, or “pyroxyle:”—and according to Pelouze, consists of $C_{29.66}H_{3.70}O_{50.22}N_{10.36}$.

216. *The gun cotton* of Schönbein is one form of this substance. It is prepared, by immersing clean cotton, for about fifteen minutes, in a mixture consisting of equal parts concentrated nitric and sulphuric acids—none of the cotton being left above the liquid, lest an accident should occur. The acid being pressed out, the cotton is washed with water, until it ceases to redden litmus paper: and is then dried, at a temperature not exceeding 212° , a free current of air being made to pass over it. The formation of lumps, which are highly explosive, must, as much as possible, be prevented. Cotton wool, according to Pettenkofer, consists of $C_{44.5}H_{6.1}C_{49.4}$; and gun cotton, according to Schönbein, and Böttiger, of $C_{27.43}H_{3.54}O_{54.77}N_{14.26}$. The latter is thought, by some, to consist of an atom of cotton, and two atoms nitric acid, minus two atoms hydrogen. $C_{12}H_{10}O_{10} + 2NO_5 - 2H = C_{12}H_8O_{20}N_2$.

217. Gun cotton explodes by percussion, but not by friction. It explodes at the temperature of 356° , which is less than that required by gunpowder: and, hence, it may be fired, on gunpowder, without ignition being communicated to the latter—indeed it has sometimes exploded, at less than 212° . Its explosion produces carbonic oxide, carbonic acid, cyanogen, nitrogen, nitric oxide, and water—without any residue; and is accompanied by very little smoke. Its force is four times as great,

* Xulon, wood. Gr.

as that of gunpowder: and, hence, it is highly efficient in blasting rocks. But it ignites so rapidly, and is so very hygro-metric, that it is not likely [inorg. chem. 238] to be much used, in war. Its effect is greatly increased, by impregnating it with chlorate of potash—which, also, prevents the trifling injury that it does to firearms. It is insoluble in water; but may be purified, by solution in acetic ether. It differs from xylodine, in not being affected by acids.

218. **EXTRACTIVE MATTER.**—If a vegetable juice is evaporated, by a gentle heat, the oxygen of the air, acting upon it, forms a brownish black precipitate:—this is “extractive matter.” It is sparingly soluble in water; but is easily dissolved by alkalies. It is very similar to the substance, which is produced by the action of the atmosphere, on animal, and vegetable bodies.

219. **GLUTEN** is the residue of wheaten flour, after the starch has been washed away. It may be obtained, by washing wheaten flour, in a linen bag, as long as any thing is removed: and treating what remains with boiling alcohol:—when water is added, and the alcohol is distilled off, the gluten is deposited in large coherent flakes. Boiling, with water, dissolves out the *mucin* from the gluten.

220. Gluten contains nitrogen. It is of a pale yellow colour: and, when soft, is elastic. It is soluble in acetic acid, and alkalies: and is precipitated, in combination with oxides, by earthy, or metallic salts. It gives a slightly soluble precipitate, with sulphuric acid.

221. **VEGETABLE ALBUMEN*** is the residue, when the gluten has been dissolved out [219] by boiling alcohol. It contains nitrogen. Unlike gluten, it is not elastic, when soft. To a certain extent, it is soluble in water: and the solution is coagulated by heat. It dissolves in alkalies: and is precipitated by earthy salts, and by the acids—except the phosphoric, and acetic. Wood is preserved from decomposition, by combining the albumen present in its juices with a metallic salt.

222. **LEGUMINE** is obtained, by diffusing powdered peas through water: then pouring off, and evaporating the fluid:—the legumine rises to the surface, in transparent pellicles. It contains nitrogen, and sulphur. It is soluble, in vegetable, and is precipitated, by mineral acids. It is dissolved by alkalies: and is thrown down again, by earthy, and metallic salts. Its solution is not coagulated, by heat.

223. **FIBRINE.**—It consists of $C_{800}H_{630}O_{240}N_{100} + PS_2$, with small quantities of lime, and magnesia. It is the chief constituent of muscular fibre: and is a very important element of the blood—being contained by that fluid in solution, until it coagulates. It

* *Albumen*, white of egg. *Lat.*

is procured, by agitating fresh drawn blood, with a bundle of twigs : then washing what adheres to the twigs—to remove the colouring matter : and digesting it in alcohol or ether—to take away traces of fat. When dried, it is without colour, taste, or smell :—unless fat is present, it is not transparent. It absorbs water, so as to recover its softness, and flexibility. With oil of vitriol, as also with monobasic, and bibasic phosphoric acid, it forms a yellow transparent jelly. The latter is a compound of fibrine and the acid : and is soluble, in water, when the excess of acid is washed away :—water being added, it becomes hard. Fibrine, acted upon by nitric acid, forms *xanthoproteic acid* ($C_{34}H_{25}O_{12}N_4$), a yellow powder. Strong hydrochloric acid, causes it, when quite dry, to swell up, and then dissolves it :—the solution is a dark blue liquid, which gives a precipitate with ferrocyanide of potassium. It is soluble, in tribasic phosphoric, and in acetic acid ; and the solutions are precipitated, by mineral acids, and by caustic potash—the precipitate, formed by the latter, being soluble in excess. A solution of fibrine, in dilute caustic potash, is almost neutral. It is coagulated by alcohol, and acids ; but not by heat. Dissolved in a solution of saltpetre, it is coagulated by heat, alcohol, and acids : and is precipitated, by ferrocyanide of potassium, and the salts of mercury, lead, and copper. There is a great resemblance between fibrine, and gluten [220].

224. ANIMAL ALBUMEN.—Its constitution is $C_{900}H_{620}O_{240}N_{100} + PS_4$ —along with more lime, &c., than fibrine. Albumen is found in the white of eggs, serum of the blood, fluid of dropsy, &c. It assumes both a soluble, and an insoluble form.

Soluble albumen is obtained, by evaporating to dryness, either white of egg, torn up by trituration with fragments of glass, or serum of the blood, at a temperature not higher than 120° . The result, being digested in alcohol, or ether, will be pure albumen ; and without colour, taste, or smell. At first, it swells up, and then dissolves in cold water : and the solution coagulates, between 140° and 150° . If dilute, it does not coagulate, at a temperature lower than 165° —nor, if the quantity of albumen is very small, below 212° . It is coagulated by tannic acid, and minute quantities of kreosote. Once coagulated, it is insoluble. If quite dry, it may be heated to 212° , without losing its solubility. In solution, it is thrown down by alcohol, acids, and metallic salts :—when the precipitate is formed by the latter, it consists of albumen, combined with the acid, and albumen combined with the oxide.

225. *Coagulated albumen* is procured, by coagulating serum of the blood with hydrochloric acid, washing the coagulated mass with acidulated water, dissolving it in water, and decomposing the solution with carbonate of ammonia—which separates

the albumen, as a white flocculent substance. It is yellow and transparent, when dry: and very much resembles fibrine, in its properties, &c.

226. Albumen is kept in the liquid state, in white of eggs, by the presence of soda. Unless coagulated, it putrefies rapidly, if exposed to the air. In the state of concentration, in which it is found in the serum of the blood, it dissolves some metallic oxides—particularly protoxide of iron. It is, therefore, the solvent of the iron, which [inorg. chem. 172] performs so important a function, in respiration. Seven, or eight parts, hydrochloric acid, and one of coagulated albumen, strike an intense blue colour—particularly if heated to 80°. Corrosive sublimate is a most delicate test for albumen; and detects it, when dissolved in 2,000 parts water. It is [inorg. chem. 576] an antidote for corrosive sublimate; and, also, for the salts of copper—forming with them a white, and harmless precipitate. Animal, and vegetable albumen are, in all respects, very similar.

227. CASEINE :^{*}— $C_{400}H_{310}O_{120}N_{50}+S$, with two atoms bibasic phosphate of lime. It is one of the constituents of cheese: and may be obtained, by adding sulphuric acid to skimmed milk. The caseine is precipitated, in combination with the acid: and, being washed with water, is digested with carbonate of barytes. The resulting solution of caseine, in water, is filtered, and alcohol is added—to throw down the caseine. The latter is purified, by digesting with ether—to remove any trace of butter.

228. Caseine dissolves in water, forming a thick mucilage, having the smell of boiled milk. It dries into a thick amber-coloured mass, without losing its solubility. Its solution is coagulated by alcohol, and acids. When coagulated by *rennet*, it cannot be distinguished from coagulated albumen.

It is supposed that caseine consists of *tyrosine* ($C_{16}H_9O_5N$), and *leucine* ($C_{12}H_{12}O_4N$). The former may be obtained, by fusing caseine with caustic potash: then dissolving the residue in water, and adding acetic acid to the solution. Tyrosine separates, in the form of brilliant needles: and leucine may be obtained, from the mother liquor, by evaporation. Caseine seems identical with legumine [222].

229. It has been supposed by Müllder, that fibrine, albumen, and caseine, with the corresponding vegetable elements, are compounds of sulphurets of phosphorus, and a substance named by him, *protein* ($C_{40}H_{31}O_{12}N_5$). The latter may be obtained, by digesting fibrine, or albumen, in water, alcohol, and ether—to remove all substances which are soluble: then in dilute hydrochloric acid, to take away the earthy salts: dissolving the

^{*} *Caseum*, cheese. *Lat.*

residue in caustic potash, and heating the solution to 120° —to form phosphate of potash, and sulphuret of potassium, with the phosphorus and sulphur: and, finally, precipitating the protein, with acetic acid—which, as it would re-dissolve the precipitate, is not to be added in excess. The resulting grayish, white, gelatinous flocks, according to Mülder, form when dried an amber-coloured powder which by absorbing water, regains the appearance it had, before exsiccation.—There are probable reasons, against Mülder's opinion.

230. From the great resemblance, if not identity, of the most important vegetable, and animal substances, it follows that, in reality, the same principles constitute the food of both graminivorous, and carnivorous animals.—Where the vegetable ends, the animal begins: and thus proceed the formation of numerous, and complicated compounds. There are, in the vegetable, and animal kingdoms, many corresponding bodies, besides those to which I have directed attention.—The fat of beef, and mutton, is present in cocoa beans; human fat, in olive oil; the principal ingredient of butter, in palm oil; horse fat, and train oil, in certain seeds, &c.

231. VEGETABLE JELLY, or *pectin*:— $C_{24}H_{17}O_{22}$. It is found, in almost all parts of every kind of plant: and may be obtained, by filtering the expressed juice of beet, celery, currants, &c., and mixing it with alcohol. After some hours, the pectin will separate, as a jelly: and, being washed with alcohol, must be dried with a moderate heat. It is without colour, taste, or smell: and forms a jelly, with 100 parts water. It gives precipitates, with salts of barytes, copper, lead, and peroxide of iron. It is changed, by boiling with strong acids, or bases, into *pectic acid*—isomeric with pectin. When the latter, or pectic acid, is boiled with an excess of potash, until the liquid ceases to give a precipitate with hydrochloric acid, *metapectic acid*, which is five-basic—and is, also, isomeric with pectin—is produced.

232. GELATINE. Its constitution, according to Mülder, is $C_{13}H_{10}O_5N_2$. It does not—as might at first be supposed, on account of the resemblance between vegetable, and animal albumen, &c. [230]—at all correspond with vegetable jelly. It exists in the skin, cartilages, tendons, membranes, &c. Gelatine gives toughness to bones; and the salts of lime, strength. Half the bones of an ox, are gelatine. It is very abundant, in the bones of young animals:—which, therefore, are the less easily fractured. Fish bones, however, are weak, from containing excess of gelatine. A bone will perfectly retain its shape and appearance, when its earthy salts are dissolved out with hydrochloric acid: but will have become quite flexible. Gelatine is found, abundantly, in commerce. It is obtained, in an impure state,

as common *glue*, from parchment, skins, &c.; as *isinglass*, from the sounds of fish—particularly of the sturgeon; as *confectioner's jelly*, from calves' feet. It is separated from the albumen, with which it is associated, by boiling.

233. When pure, it is transparent, and without colour. It swells up in cold, but dissolves easily in hot water: and the solution, on cooling, forms a "jelly," if it contains one part in 100, of gelatine. It is insoluble in alcohol; but dissolves readily, in most dilute acids, and in the fixed alkalies—from which it is not precipitated, by acids. With tannic acid [98], it constitutes leather: and it forms a compound ($C_{52}H_{40}O_{20}N_8 + ClO_4$) with chlorine. It is supposed, by some chemists, to be a product of the decomposition of albumen, or fibrine, by boiling water, rather than a distinct body.

234. OZMAZOME* is obtained, by boiling down meat broth, to dryness: treating the residue with alcohol, and filtering.—It will be left on the filter. When heated, it emits the odour of roast meat, the smell of which is due to its presence.

235. VEGETABLE ALKALIES. Besides acids having compound radicals, there are alkalies having compound bases. They all contain nitrogen: and are very important, since they confer on the plants, from which they are derived, their most active properties. The chief of them are—nicotine ($C_{10}H_7N$), found in tobacco; coneine ($C_{17}H_{17}N$), in the hemlock; menispermine ($C_{18}H_{12}O_2N$), in the capsules of the *coccus indicus*, &c.; chinchonine ($C_{20}H_{12}ON$), quinine ($C_{20}H_{12}O_2N$), and aricine ($C_{20}H_{12}O_3N$), in the bark of the various species of *cinchona*; sabadilene ($C_{20}H_{13}O_5N$), jervine ($C_{30}H_{23}O_2N$), and veratrine ($C_{34}H_{21}O_6N$), in the roots of the *veratrum album*, &c.: codeïne ($C_{36}H_{21}O_6N$), thebaine ($C_{25}H_{14}O_3N$), morphia ($C_{34}H_{20}O_6N$), and narcotine ($C_{46}H_{27}O_{14}N$), in opium; harmaline ($C_{24}H_{13}ON_2$), in the seeds of the *peganum harmala*; delphinine ($C_{27}H_{19}O_2N$), in the seeds of the *stavesacre*; atropine ($C_{34}H_{23}O_6N$), and belladonnine (composition not yet ascertained), in the *atropa belladonna*; chelidonine ($C_{40}H_{20}O_6N_3$), and chelerythrine, in the roots of the *chelidonium majus*; strychnine ($C_{44}H_{22}O_4N_2$), and brucine ($C_{48}H_{26}O_8N_2$), in the *nux vomica*, &c.:—solanine ($C_{48}H_{73}O_{28}N$), in the berries of the *solanum nigrum*, in the berries, leaves, &c., of the potato [21]. Also, colchicine, in the seeds of the meadow saffron; emetine, in *ipecacuana*; aconitine, in the monk's hood; daturine, in the seeds of the thorn apple; hyocyamine, in the henbane; cissampeline, in the roots of the *cissampelos pareira*; glaucine, in the horned poppy, &c.—The constitutions of these latter have not been determined.

Tannic acid, and the soluble tannates, throw down almost all

* *Osmē*, odour; and *zōmos*, broth. Gr.

the vegetable alkalies, as white pulverulent compounds, insoluble in water, but soluble in acetic acid.

236. SALICINE :*— $C_{26}H_{18}O_{14} + 2Ag$ when crystallized. It is found in the leaves, and bark, of many trees—particularly, in those species of sallow which have a bitter taste. It may be obtained, by boiling the bark three or four times with water; reducing the decoction, by evaporation, to three times the weight of the bark employed, and digesting it, for twenty-four hours, with oxide of lead; then evaporating the clear liquid, to the consistence of syrup. After some days, there will be a mass of crystalline fibres, which is to be dried by pressure: and then, purified by re-solution, and digestion with animal charcoal.

237. Salicine crystallizes, when quite pure, in plates, or prisms. It dissolves, in eighteen parts cold, and in one part hot water:—it is soluble, also, in alcohol. It has a very bitter taste. It fuses at 212° , and crystallizes again, on cooling. If boiled with dilute sulphuric acid, it forms grape sugar, and *saliretine* ($C_{14}H_6O_2$). $C_{26}H_{18}O_{14} + 2HO = C_{12}H_{11}O_{11} + 3HO + C_{14}H_6O_2$. It gives, with basic acetate of lead, a white precipitate ($C_{26}H_{18}O_{14} + 3PbO$).

238. CAFFEÏNE, or THEÏNE:— $C_8H_5O_2N_2 + Ag$. It is found in the coffee berry, tea leaf, &c.: and may be obtained, by boiling raw coffee, or green tea, in water; adding subacetate of lead to the decoction, as long as a coloured precipitate is thrown down: and removing the excess of lead, by sulphuretted hydrogen. When the filtered liquor is evaporated, and cooled, caffeine will separate, in the crystalline form. If coloured, it must be boiled, with oxide of lead and ivory black; and re-crystallized. One pound of coffee will yield about fifteen grains caffeine.

239. Caffeine is in the form of brilliant, long needles; it is soluble in fifty parts cold, and in less hot water: but is insoluble in alcohol. It has a bitter taste. Caffeine probably assists in the secretion of bile:—it does not seem to have much to do with the flavour of coffee. It contains much more nitrogen than any other vegetable substance.

240. PIPERINE:†— $C_{34}H_{19}O_6N$. It is found in pepper; and is obtained, by digesting that substance in spirit of wine: evaporating the liquor, to the consistence of an extract; digesting the residue in a solution of caustic potash—to remove the resin: and dissolving what is left, in alcohol. If the solution is allowed to evaporate spontaneously, piperine will separate, in transparent, rhombic prisms. It is without taste, or smell. It fuses at 212° : and becomes red, when treated with nitric acid.

241. THE PUTREFACTIVE FERMENTATION. It should scarcely be considered as a species of fermentation: and is a complete

* *Salix*, a sallow. *Lat.* † *Piper*, pepper. *Lat.*

breaking up of the body, more simple compounds being produced with its constituents. Those substances, only, that contain oxygen and hydrogen in the proportions which form water, are disposed to putrefy:—and the tendency becomes very great, when bodies, already in a state of putrefaction, are present.—Thus a bad apple, or an unsound potato, will destroy a large heap of apples, or potatoes. The motion, already existing in the atoms of one substance, overcomes the inertia of those in the other; and causes affinities, of themselves *almost* sufficiently powerful, to come into action. In a similar way, the percussion of a bar of steel will generate, or destroy magnetism [mag. 24]—by enabling the magnetism of the earth, not quite powerful enough of itself, to produce a magnetic effect on the particles of steel.

242. The action of several poisons is due to decomposition being produced in this way:—of all those, for instance, the dangerous properties of which are removed by alcohol, without the latter becoming deleterious: and of those—such as decayed sausages, the virus of the small-pox, &c.—from which the poisonous matter cannot be extracted.

243. It is by no means necessary, that a fermenting substance should pass through all the, generally speaking, prior species of fermentation. Acetification, or putrefaction, may take place, without any other fermentation having preceded it.—At least, the different kinds, may succeed each other so rapidly, that it will be impossible to distinguish them.

244. Putrefaction is prevented by certain substances; and requires certain conditions.—If meat is steeped, for a few moments in *kreosote** ($C_{14}H_9O_2$), it will not putrefy, even in the sun. This substance is one of the products of the destructive distillation of wood: and may be obtained, by continually rectifying coal tar, until the oil which distils over has become heavier than water. When this oil is digested, with a solution of caustic potash, the kreosote it contains, is dissolved, and separates if the liquid—having been rendered brown by exposure to the atmosphere—is neutralized with an acid. It must be redissolved, in caustic potash, and reprecipitated as before, until exposure to the air no longer discolours the solution. Kreosote is an oily, colourless liquid, having a penetrating odour of smoke, and an acrid taste. Its specific gravity is 1.037. It boils at 400° : and burns with a smoky flame. 100 parts water dissolve a little more than one of kreosote: and ten parts of the latter dissolve one of the former. It mixes, in every proportion, with ether, alcohol, and acetic acid.

245. Heat is necessary, for all kinds of fermentation: and the nature of the latter is, to a great extent, determined, by the

* *Kreas*, flesh; and *sōzo*, I save. Gr.

temperature.—Peat bogs are found only in countries, where the climate is not warm enough to cause total decomposition of the vegetable matter. Putrefaction cannot take place, under 32° . Salmon, taken in the river Bann, &c., is exported without salt, being packed in ice. Fresh meat is brought in ice, from America. A large animal was found, some time since, in the polar regions, perfectly preserved by the cold: although it must have been dead, a great number of centuries—the very species being long since extinct.

246. Neither can putrefaction take place, if the temperature is higher than 182° .—The time, during which meat will keep may be prolonged if, after being killed for some time, it is boiled. The high temperature will stop incipient putrefaction, by coagulating the azotized substances.

247. Putrefaction requires the presence of moisture.—Salt preserves meat, by combining with the water necessary for its putrefaction. Alcohol, and sugar also, would have the same effect: and for a similar reason.—The affinity of salt for water, makes us thirsty, by taking up that, which moistened the coatings of the stomach: and, since only a small quantity is absorbed, an excess of it, passing in the state of solution into the intestinal canal, will dilute what is there, and act as a purgative.

248. The presence of air, is necessary for putrefaction.—Dressed meats, soups, &c., are carried, perfectly fresh, to the most distant regions, in vessels hermetically sealed, and containing no atmospheric air. Eggs may be preserved for a considerable time, by rubbing them with an unctuous substance, which, by stopping the pores of the shell, excludes the air. Putrefaction is a most powerful deoxidizing agent:—it will change yellow, into black oxide of iron: and sulphate of iron, into sulphuret. When enormous masses of vegetable matter, have lain under great pressure, and without access of air, peculiar changes occur, coal being formed, and carbon deposited.—It is easy, by the aid of the microscope, to detect even the leaves, &c., of which the coal consists; and to determine the species of the plants, it contains.

249. Coal is found, in some cases, to have been exposed to intense heat, due to the proximity of igneous rocks; and the expulsion of the volatile elements has produced *anthracite**—a kind of mineral coke, of which, Kilkenny coal, is a familiar example.

250. Analyses of coal, give different results. This arises, from difference in the woods which constitute it; and from the particular stage, to which its gradual formation happens to have reached: &c.—

* *Anthrax*, a coal. Gr.

Supposing oak wood to be $C_{36}H_{22}O_{22}$, and that one atom of its hydrogen, and three atoms of its carbonic acid are removed, the result will be wood coal, $C_{33}H_{21}O_{16}$. But, supposing that three atoms carburetted hydrogen, three atoms of water, and nine atoms of carbonic acid are removed, it will be $C_{24}H_{13}O$ —isomorphous with Newcastle coal, splint coal, and cannel coal, from Lancashire.

251. The mode, in which coal-fields have, most likely, been formed, is exemplified in the enormous masses of drifted wood, which are deposited at the mouths of the great American rivers. These will, it is probable, in time, be covered with sand and rocks; in some instances, they will be acted upon by volcanic heat; and all, or most of them may become, hereafter, the supply of future, and far distant generations. It can scarcely be doubted that our own coal-fields were formed in this way, when these islands were portions of a mighty continent, whence they have been severed, by the gradual inroads of the sea, or by some sudden, and terrible convulsion.

252. If animal matter is kept, for a long time, without contact with air, certain remarkable changes occur. These were examined by Fourcroi, when the bodies were removed from the burial place *Des Innocens*, at Paris. Immense multitudes of human beings had been interred, in the same pits; and, except the hair, and bones, the entire mass was converted into an ammoniacal soap [148].

253. Transformations occur, during the putrefaction of animal, and vegetable substances, which, occasionally, produce poisons.—Thus putrid meat, mouldy bread, &c., have been known to cause dreadful, and even fatal, consequences. Also, wounds that are received, during dissection, and that cause the juices of the dead, to come in contact with those of the living body, are of the most dangerous character. In certain cases, the poison generated, is gaseous:—thus, what is emitted when the stomach bursts, after death.

254. LAST PRODUCTS OF DECAYED VEGETABLE MATTER. Wood is, sometimes, changed into a white friable substance—seen in the interior of decayed trees. It consists of $C_{33}H_{27}O_{24}$: and is formed, by the combination of lignine, with oxygen and the constituents of water, carbonic acid being evolved.

$$C_{36}H_{24}O_{24} + O_3 + 3HO = C_{33}H_{27}O_{24} + 3CO_2.$$

255. When wood has been long acted upon by air and moisture, *ulmine** ($C_{40}H_{14}O_{12}$), and ulmic acid ($C_{40}H_{12}O_{12}$ —which is isomeric with saccharohumic acid [171])—are produced. They are generated, by the woody fibre absorbing oxygen, carbonic acid and water being set free. Thus $4C_{12}H_8O_3 + O_{14} = C_{40}H_{14}O_{12} + 8CO_2 + 18HO$. The ulmic acid is insoluble in water, and alcohol:

* *Ulmus*, an elm; because originally obtained from that tree in a state of decay.

but dissolves, in alkaline solutions. When found in nature, it is combined with ammonia—which it retains so obstinately, that, in the attempt to separate them, by means of caustic potash, it is partially decomposed.

256. When vegetable, &c., substances are transformed into the organic parts of vegetable mould, a number of acids, &c., are produced. The most important of these have been divided by Mülder, into the *humic*, and *crenic* groups. The former, includes humous acid or *humine* ($C_{40}H_{12}O_{12}$), and *ulmine* ($C_{40}H_{14}O_{12}$), *humic* ($C_{40}H_{12}O_{12}$) and *ulmic acid* ($C_{40}H_{12}O_{12}$), &c. Humic acid, though isomeric with the humine of peat, is distinguished from it by absorbing ammonia with great avidity, and combining with it so strongly that they cannot be separated. The different kinds of humic acid vary, according to the sources whence they are derived:—obtained from black turf, its constituent is $C_{40}H_{15}O_{15}$ —the same as that of saccharohumine [171]. When precipitated from its solution, in alkalies, by sulphuric acid, it is soluble in 2,500 times its weight of water, and forms compounds with the alkalies, lime, and magnesia, of the same solubility. It is not precipitated by acetic acid. After having been dried or exposed to a freezing temperature, it is insoluble.

Geic acid* ($C_{40}H_{12}O_{14}$) is formed from humic; *appocrenic acid* ($C_{48}H_{24}O_{32}$) from geic; and *crenic† acid* ($C_{24}H_{12}O_{16}$) from appocrenic:—in the upper layer of the soil, appocrenic is formed from crenic acid. According to Mülder, the ammonia of the atmosphere, even without ammoniacal manure, would slowly form ammoniacal salts, with the crenic, and appocrenic acids. Crenic, and appocrenic acid, form salts, also, with the fixed alkalies, lime, magnesia, &c. Appocrenic acid being five-basic, is highly valuable: since it is capable of supplying plants, with several bases, at once. Crenic acid, is four basic.—Further decomposition changes crenic acid into carbonic acid and water.

* *Gē*, the earth. *Gr*.

† *Krēnē*, a spring, *Gr*.; because first obtained from spring water.

CHAPTER VIII.

Constitution of the most important Vegetable Substances, 257.—Manures, 262.—Animal Manure, 265.—Vegetable Manures, 274.—Mineral Manures, 275.

257. CONSTITUENTS OF THE MOST IMPORTANT VEGETABLE SUBSTANCES. Agriculture cannot be advantageously pursued, without a knowledge of the elements of those plants which are usually cultivated, of the manures which are most commonly employed, and of the methods, by which the constituents of the soil, &c., can be discovered.

Earthy and metallic substances are obtained only from the soil. Until a comparatively recent period, it was supposed that, as they were found but in small quantities, they were present by *accident*, and did not constitute any essential portion of the vegetable. It is now, however, universally admitted that the necessity of replacing them, when they have been removed, is the principal reason for the application of manures. Some crops are evidently better suited than others to particular soils; but a soil, not naturally adapted to a certain plant, may often, by the judicious application of some substance, be made to afford it in abundance. Chemistry alone can supply the knowledge required in these circumstances. By means of it, we ascertain the elements which are necessary to the different vegetables; the constituents of different soils; and the peculiar properties of the various manures. Much depends on climate and situation, which are beyond our control: but much, also, on the nature of the ground, which may be considered, to a great extent, under the command of industry and science. An accurate acquaintance with the elements, contained in the various kinds of agricultural produce, and their relative amounts, is indispensable. Almost all of them have been carefully examined, by Boussingault, and others; and the results obtained are most valuable. The analyses of eminent chemists do not always agree:—but this is to be expected, since [23] the constituents of plants are not absolutely invariable.

The following is the amount of ashes, in 100 parts of the most ordinary trees, &c.—

TREES.

	Species.		Authority.
Alder, young,	.	0·35	} Karsten.
— old,	.	0·40	
Ash,	.	2·30	Mollerat.
Red Beech, young,	.	0·37	} Karsten.
— old,	.	0·40	
— bark,	.	6·62	Hertwig.
Birch, young,	.	0·25	} Karsten.
— old,	.	0·30	
Elm,	.	2·28	Mollerat.
Lime,	.	0·40	} Karsten.
Oak, young,	.	0·15	
— old,	.	0·11	} Saussure.
— branches,	.	0·4	
— bark,	.	6·0	
— leaves,	.	5·5	} Mollerat.
Poplar,	.	1·306	
Pine (<i>P. sylvatica</i>), young,	.	0·12	} Karsten.
— old,	.	0·15	
— needles,	.	2·60	Saussure.
— seeds,	.	4·98	Fresenius and Wills.
Scotch Fir (<i>P. picea</i>),	.	0·15	Karsten.
— seeds,	.	4·44	Fresenius and Wills.
Fir (<i>P. abies</i>), young,	.	0·22	} Karsten.
— old,	.	0·25	
— bark,	.	1·78	Hertwig.
— needles,	.	2·90	Saussure.

SHRUBS.

Barberry,	.	0·71	Mollerat.
Blackberry,	.	0·76	Mollerat.
Broom,	.	1·48	Mollerat.
Elder,	.	1·64	Berthier.
Hazel,	.	0·50	Saussure.
Heckle,	.	1·66	Mollerat.
Heath,	.	1·41	Mollerat.
Juniper,	.	1·84	Mollerat.
Rose (wild),	.	0·71	Mollerat.

HERBS.

Fern,	.	2·75	Karsten.
Maize straw,	.	12·20	Saussure.
Nettle,	.	10·67	Pertuis.
Oat straw,	.	5·10	Boussingault.
Pease holm,	.	8·10	Saussure.
Potato straw,	.	15·00	Berthier.
— leaves,	.	1·15	Mollerat.
Rushes,	.	4·33	Pertuis.
Rye straw,	.	0·30	Karsten.
Thistles,	.	4·03	Pertuis.
Wheat straw,	.	4·40	Berthier.

258. Constituents of the ashes, according to Berthier—

Soluble.	Alder.	White Beech.	Red Beech.	Birch.	Elder.
Carbonic acid, . . .	—	—	3·65	2·72	7·71
Sulphuric acid, . . .	1·24	—	1·19	0·37	2·06
Hydrochloric acid, . . .	0·06	—	0·85	0·03	0·13
Silicic acid, . . .	—	—	0·16	0·16	0·06
Potash, . . . }	—	—	10·45	12·72	21·54
Soda, . . . }	—	—	10·45	12·72	21·54
	18·8	19·22	16·30	16·00	31·50
Not soluble in water.					
Carbonic acid, . . .	25·17	26·92	27·53	26·04	22·06
Phosphoric acid, . . .	6·25	8·11	4·77	3·61	5·83
Silicic acid, . . .	4·06	4·05	4·85	4·62	2·25
Lime, . . .	40·76	31·31	35·66	43·85	34·57
Magnesia, . . .	2·03	6·33	5·86	2·52	1·76
Oxide of iron, . . .	2·92	1·30	1·25	0·42	0·08
Oxide of manganese, . . .	—	2·76	3·77	2·94	1·26
	81·20	80·78	83·70	84·00	68·50

The difference between their total amounts, and 100 is the loss, if any; and, sometimes, the relative weights of constituents, not examined.

Soluble.	Fir.	Lime.	Mulberry.	Nut tree.	Oak.
Carbonic acid, . . .	7·76	2·96	5·82	3·11	2·88
Sulphuric acid, . . .	0·80	0·81	2·09	0·78	0·97
Hydrochloric acid, . . .	0·08	0·19	1·01	0·08	0·01
Silicic acid, . . .	0·26	0·17	—	0·08	0·02
Potash, . . . }	16·80	6·55	{ 13·16 }	{ 11·27 }	8·11
Soda, . . . }	16·80	6·55	{ 2·91 }	{ 11·27 }	8·11
	25·70	10·8	25·00	15·40	12·00
Not soluble in water.					
Carbonic acid, . . .	17·17	35·75	31·75	32·33	34·99
Phosphoric acid, . . .	3·14	2·51	1·36	4·19	0·71
Silicic acid, . . .	5·97	1·80	2·19	3·67	3·36
Lime, . . .	29·72	46·53	34·85	37·06	48·41
Magnesia, . . .	3·28	1·97	3·48	3·84	0·53
Oxide of iron, . . .	10·53	0·09	0·38	3·50	—
Oxide of manganese, . . .	4·48	0·54	0·98	—	—
	74·30	89·20	75·00	84·60	88·00

Soluble.	Pine.	Fern.	Potato straw.	Wheat straw.
Carbonic acid,	2.89	4.35	0.26	a trace.
Sulphuric acid,	1.67	1.62	0.97	0.20
Hydrochloric acid,	0.92	3.19	0.50	1.31
Silicic acid,	0.18	—	—	3.53
Potash,	4.41	19.84	2.47	5.05
Soda,	3.53			
	13.60	29.00	4.20	10.10
Not soluble in water.				
Carbonic acid,	32.77	17.96	—	—
Phosphoric acid,	0.91	5.68	—	1.08
Silicic acid,	4.19	15.48	36.4	73.36
Lime,	38.51	30.39	—	5.72
Magnesia,	9.56	0.50	—	—
Oxide of iron,	0.09	0.50	—	2.42
Oxide of manganese,	0.36	0.50	—	7.25
				some potash.
	86.40	71.10	95.80	89.90

According to Hertwig—

Soluble.	Bean Straw.	Pea Straw.
Carbonate of potash,	13.32	4.16
Carbonate of soda,	16.08	8.27
Chloride of sodium,	0.28	4.63
Sulphate of potash,	3.24	10.75
	32.91	27.82
Not soluble in water.		
Carbonate of lime,	39.50	47.81
Magnesia,	1.92	4.05
Phosphate of lime,	6.43	5.15
Phosphate of magnesia,	6.66	4.37
Basic ditto of iron,	3.49	{ 0.90
— of alumina,		
Silicic acid,	7.97	7.81
	65.97	72.18

According to Fresenius, rye straw consists of—

Soluble.	
Silicate of potash, . . .	6.88
Sulphate of potash, . . .	1.75
Chloride of potassium, . .	0.25
———— of sodium, . . .	0.56
Silicate of lime, . . .	4.19
Magnesia, . . .	0.76
Phosphate of lime, . . .	2.50
———— of magnesia, . .	1.28
———— of iron, . . .	1.57
———— of manganese, a trace.	—
	19.47
Not soluble in water.	
Silicate of potash, . . .	9.21
———— of lime, . . .	3.43
———— of magnesia, . .	1.16
Phosphate of iron, . . .	1.63
———— of manganese, a trace.	—
Carbon, . . .	0.94
	80.26

According to Kane—

Flax Plant.	
Carbon, . . .	38.72
Hydrogen, . . .	7.33
Oxygen, . . .	48.39
Nitrogen, . . .	0.56
Ashes, . . .	5.00
	100.00
Ashes.	
Carbonic acid, . . .	16.95
Sulphuric acid, . . .	2.65
Phosphoric acid, . . .	10.84
Silicic acid, . . .	21.35
Chlorine, . . .	2.41
Potash, . . .	9.78
Soda, . . .	9.82
Lime, . . .	12.33
Magnesia, . . .	7.79
Oxides of iron, and alumina, . . .	6.08
	100.00

259. The following may be considered, as an average of the constituents, in 100 parts, of the most common vegetable substances :—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Water.	Ashes.
Clover hay, . . .	37.3	3.8	30.0	2.0	21.0	5.9
Jerusalem artichokes, . .	9.1	1.1	9.1	0.3	79.2	1.2
Stems of ditto, . . .	39.8	4.7	39.8	0.3	12.9	2.5
Mangel-wurzel, . . .	5.2	0.8	5.2	0.2	87.8	0.8
Oats, . . .	40.1	5.1	29.1	1.8	20.8	3.1
Oat straw, . . .	35.7	3.9	27.8	0.3	28.7	3.6
Peas, . . .	42.5	5.7	36.6	3.8	8.6	2.8
Pea straw, . . .	40.3	4.5	31.4	2.0	11.8	10.0
Potatoes, . . .	10.6	1.4	10.8	0.3	75.9	1.0
Rye, . . .	39.1	4.8	36.0	1.5	16.6	2.0
Rye straw, . . .	40.6	4.6	33.0	0.2	18.7	2.9
Turnips, . . .	3.2	0.4	3.2	0.1	92.5	0.6
Wheat, . . .	39.4	5.0	37.1	3.0	14.5	2.0
Wheat straw, . . .	35.8	3.9	28.8	0.3	26.0	5.2

260. The following may be considered, an average of the constituents, in 100 parts of the inorganic matter, found in the most common vegetable substances :—

	Carbonic acid.	Sulphuric acid.	Phosphoric acid.	Silicic acid.	Chlorine.	Potash.	Soda.	Chloride of potassium.	Chloride of sodium.	Lime.	Magnes.	Oxide of iron.
Barley, . . .	—	0.79	31.69	32.73	—	20.77	4.56	—	—	1.48	7.45	0.51
Barley straw, . .	—	1.63	3.08	70.58	0.97	6.31	0.61	—	—	9.53	3.22	0.83
Beans, . . .	1.94	4.50	31.87	0.88	—	42.13	0.90	0.34	1.90	8.65	6.55	0.36
Bean straw, . . .	22.73	3.21	7.35	3.86	—	21.26	4.56	0.90	9.05	21.29	4.88	0.90
Cabbage, . . .	—	21.48	12.37	0.75	5.77	11.70	20.42	—	—	20.97	5.94	0.60
Carrots, . . .	17.30	6.55	8.55	1.19	—	32.44	13.52	—	6.50	8.83	3.96	1.10
Clover hay (white), .	18.03	7.21	11.53	3.68	—	14.33	3.72	—	4.94	26.41	8.15	1.96
Ditto (red), . . .	16.93	4.18	6.35	3.34	—	14.85	1.40	2.96	2.36	35.39	11.22	0.97
Fax seed (Riga), . .	—	2.47	36.42	10.58	0.17	17.59	6.92	—	—	8.46	14.83	1.25
Flax straw, . . .	10.93	9.38	8.44	14.48	—	7.00	15.68	—	5.87	17.79	4.13	5.13
Mangel-wurzel, . .	18.32	3.37	3.08	2.57	—	24.79	13.75	—	29.41	1.95	2.11	0.60
Oats, . . .	—	10.45	43.84	2.67	0.26	26.18*	—	—	—	5.95	9.95	0.40
Oat straw, . . .	—	3.26	2.56	48.42	3.25	19.14	9.69	—	—	8.07	3.78	1.83
Peas, . . .	1.82	5.68	34.81	1.24	—	40.19	0.65	1.42	0.68	6.32	6.57	0.59
Pea straw, . . .	14.74	5.66	4.50	5.36	—	17.17	2.48	—	3.57	37.99	6.73	1.76
Potatoes, . . .	—	13.65	12.57	4.23	4.27	55.75	1.86	—	—	2.07	5.28	0.52
Potato straw, . . .	—	6.88	7.62	3.85	12.33	28.02	16.26	—	—	16.90	7.09	1.05
Rye, . . .	—	1.46	47.29	0.17	—	32.76	4.45	—	—	2.92	10.13	0.82
Rye straw, . . .	—	0.83	3.82	64.50	0.46	17.36	0.31	—	—	9.06	2.41	1.36
Rye grass (It.) in seed, .	—	1.31	6.32	60.62	—	10.77	0.13	—	5.58	12.29	2.64	0.30
Turnips (Swed.), . .	—	13.15	6.69	7.05	3.68	39.82	10.86	—	—	12.75	4.68	0.89
Turnip tops, . . .	—	12.52	9.29	0.86	16.05	28.65	5.41	—	—	23.27	3.09	0.86
Wheat, . . .	—	0.24	49.81	1.17	—	23.72	9.05	—	—	2.81	12.03	0.67
Wheat straw, . . .	—	5.82	3.07	65.38	—	12.44	0.16	—	—	6.70	3.81	1.30

* Including soda.

261. According to eminent chemists, 107 parts of wheat are equal as nutriment, to 111 of rye, 117 of oats, 130 of barley, 138 of Indian corn, 177 of rice, 894 of potatoes, and 1,335 of turnips. The cheapest food, therefore, is not necessarily the most economical.

262. MANURES.—Soils may have elements, which are injurious to the intended crop: or may want some of those which are required by it:—in either case, the remedy is found in manure. A soil cannot be good, if it contains more than nineteen parts, in twenty, of any one ingredient. It may have been excellent, originally: but may have become exhausted.—Meadows sometimes fail, on account of all the potash having been carried off, with the hay.

263. Some manures do not require to be decomposed, artificially—sea-weed for instance; their constituents separate of themselves with sufficient facility. The less manure is decomposed, the better; since its useful elements, are, to the less extent dissipated, and lost. Hence the effect of manure, not decomposed before it is applied, is more permanent—though less rapid.

264. If the temperature of manure is higher than 100°, or, if paper, dipped in hydrochloric acid, and held over it, emits fumes of sal-ammoniac [inorg. chem. 116], we may conclude that its decomposition is proceeding too rapidly.

265. ANIMAL MANURE.—Urine is a most excellent manure, on account of the great supply of nitrogen, which it affords. That of horses, and cows, contains less nitrogen than their solid excrement. Besides nitrogen, urine supplies large quantities of the phosphates. The following is the analysis of human urine, by Berzelius:—

Urea,	30·10
Free lactic acid, lactate of ammonia—and animal matters, not separable from them,	17·14
Uric acid,	1·00
Mucus of the bladder,	0·32
Sulphate of potash,	3·71
Sulphate of soda,	3·16
Phosphate of soda,	2·94
Phosphate of ammonia,	1·65
Chloride of sodium,	4·45
Sal-ammoniac,	1·50
Phosphates of magnesia, and lime—with a trace of fluoride of calcium,	1·00
Siliceous earths,	0·03
Water,	933·00

1000·00

The analysis, by Thompson, is as follows :—In 1000 parts

Phosphate of lime,	0.209
Phosphoric acid,	1.131
Sulphuric acid,	0.481
Chlorine,	5.782
Uric acid,	0.242
Soda,	4.610
Potash,	2.051
Ammonia,	0.130
Urea,	23.640
	<hr/>
	38.276

And he supposes them combined as follows :—

Urate of ammonia,	0.298
Sal-ammoniac,	0.459
Sulphate of potash,	2.112
Chloride of potassium,	3.674
Chloride of sodium,	15.060
Phosphate of soda,	4.267
Phosphate of lime,	0.209
Acetate of soda,	2.770
Urea, with colouring matter,	23.640
	<hr/>
	52.489

The rest of the weight being water, and free acid—perhaps lactic.

During putrefaction, urea is changed into carbonate of ammonia. The Chinese have employed urine, as a manure, from a very remote antiquity :—and they use no other, in the cultivation of corn.

266. The following is the analysis of human fæces, as given by Berzelius :—

Water,	73.3
Vegetable, and animal, remains,	7.0
Bile,	0.9
Albumen,	0.9
Peculiar extractive matter,	2.7
Salts,	1.2
Slimy matter, consisting of picromel (considered, by some chemists, as one of the constituents of bile), peculiar animal matter, and insoluble residue,	14.0
	<hr/>
	100.0

The principal value of excrement, as manure, consists in the salts, which it contains. They were found to consist of—

Carbonate of soda,	0.9
Chloride of sodium,	0.05
Ammoniacal phosphate of magnesia,	0.05
Phosphate of lime,	0.1
	<hr/>
	1.2

The ammonia, in excrements, is the more valuable since, unlike that contained in rain water, it is in a state of combination: and, but little of it, passes off.

267. Human fæces contain a variable quantity of nitrogen—but more than those of any other animal. Mixed with clay or, which is still better, with ashes, it emits no disagreeable odour. Lime, also, deprives it of smell:—the sulphuretted hydrogen produces sulphuret of calcium, but some of the ammonia is driven off.

268. It is not difficult, to make a rough estimate of the benefit, which may be expected to arise, from employing this kind of manure.—If the solid excrements of a man are supposed to be one quarter of a pound, per day, and his urine one pound and a quarter, as they contain three per cent. nitrogen, they will be equivalent to 16·425 lbs. of that element, in the year. This being enough to supply nitrogen, for 800 lbs. of wheat, rye, or oats, or for 900 lbs. of barley is, along with what is derived from the atmosphere, sufficient to make an acre of ground yield the richest crop. And, to put the matter in the simplest point of view, it may be stated that a pint of urine is equivalent to a pound of wheat. Half the nitrogen of urine will escape into the atmosphere, during its putrefaction, unless a weak mineral acid is used to neutralize it. When human excrement is employed for manure, the seeds of weeds—which pass through animals unchanged—are not sown. Hence, in China, weeds are never seen in corn fields, since they are manured [265] with urine, only. The urine of different animals, and indeed of the same animal according to its age, food, &c., varies, as to the quantity, and nature, of the solid ingredients it contains. In a year,

	lbs.		lbs.
A man produces	1,000	of urine, containing	67 solid matter.
A horse	1,000	"	89 "
A cow	13,000	"	1,023 "

1,000 parts of the urine of a man, a cow, a horse, a pig, and a sheep, contain—

	Water.	Organic Matter.	Inorganic Matter.
Man,	933·00	48·56	18·44
Cow,	921·32	41·98	36·70
Horse,	910·76	48·31	40·93
Pig,	978·80	5·24	15·96
Sheep,	960·00	28·00	12·00

The urine of man, and of the pig, is rich in phosphates: and, therefore, well adapted for seed crops.

269. The comparative amounts of the elements, in 100 parts horse, and cow dung, are as follow—

	Horse.	Cow.
Water,	78·36	79·724
Organic matter, .	19·10	16·046
Inorganic matter, .	2·54	4·230
	<hr/> 100·00	<hr/> 100·00

The inorganic matter consists of—

	Horse.	Cow.
Phosphate of lime,	5·00	10·9
Phosphate of magnesia, . . .	36·25	10·0
Carbonate of lime,	18·75	00·0
Phosphate of iron,	00·00	8·5
Carbonate of potash,	00·00	1·5
Sulphate of lime,	00·00	3·1
Silex,	40·00	63·7
Loss,	2·30	00·0
	<hr/> 100·00	<hr/> 100·00

270. The excrement of birds contains a large quantity of uric acid [62]:—it forms the white, and nearly crystalline, part: and is due to their urine, which is present, and assumes the solid form. Hence *guano*—the excrement of sea-fowl—which contains about one-fourth of its weight of uric acid, has such fertilizing properties. It is found, from analysis, to consist of—

Urate of ammonia,	9·0
Oxalate of ammonia,	10·6
Oxalate of lime,	7·0
Phosphate of ammonia,	6·0
Phosphate of magnesia and ammonia,	2·6
Sulphate of potash,	5·5
Sulphate of soda,	3·8
Sal-ammoniac,	4·2
Phosphate of lime,	14·3
Clay, and sand,	4·7
Organic substances—containing 12 per cent., insoluble in water: soluble salts of iron, in small quantities; water,	33·3
	<hr/> 100·0

The excrements of a boa constrictor, contain nine-tenths of their weight, urate of ammonia.

271. 100 parts, bones, on account of their gelatine, contain as much nitrogen as 250 lbs. of human urine. According to analysis, they are found to consist of—

Organic matter, driven off, by heat,	33·25
Phosphate of lime,	55·50
Phosphate of magnesia,	3·00
Carbonate of lime,	3·75
Salts of soda,	3·50
Fluoride of calcium,	1·00
	<hr/> 100·00

272. The following will give an idea of the relative proportions of the ingredients contained in bone, shell, and crust [inorg. chem. 319]:—

Bone—Human, and ox bones, by Berzelius—

	Human.	Ox.
Cartilage, soluble in water,	32·17	33·30
Vessels,	1·13	
Carbonate of lime,	11·30	3·85
Phosphates of lime,	54·20	59·40
Soda, and a little chloride of sodium,	1·20	3·45
	<hr/> 100·00	<hr/> 100·00

Shell—Oyster shells, according to Bucholz and Brandes—

Albuminous matter,	0·5
Lime,	54·1
Carbonic acid,	44·5
Phosphate of lime,	1·2
Alumina,	0·2
	<hr/> 100·5

Crust—Lobsters' claws, lobsters' shell, and hens' egg shell, by Pagurus—

	100 parts Lobsters' claws.	Lobsters' shell.	Hens' egg shell.
Animal matter,	17·18	28·6	4·7
Soda salts,	—	1·6	—
Carbonate of lime,	68·36	62·8	89·6
Phosphate of lime,	14·06	6·0	5·7
Phosphate of magnesia,	—	1·0	—
	<hr/> 99·60	<hr/> 100·0	<hr/> 100·0

273. I have already mentioned [232] that the relative amounts of the constituents of bones, are not always the same. They are valuable sources of phosphoric acid, which is a most important element, in plants.—Most seeds contain phosphates of lime, and magnesia: and, the larger the amount of these salts, the more nutritious the seeds are. Lentils, beans, and peas, on account of the small quantity of these substances found among their constituents, do not strengthen animals that feed on them, so much as others which contain less nitrogen. Bones appear to be improved, as manure, if deprived of their fatty matter by boiling:—it probably facilitates the decomposition of their gelatine. If rain is excluded, they may be preserved, when whole, for an indefinite period: but, if they are finely divided, and moistened, their temperature rises, and they putrefy. Cattle are slaughtered, in South America, to supply us with their bones, for the improvement of our fields. Bone manure is very conveniently prepared for use, by pouring over it, half its weight of sulphuric acid, diluted with four times its weight of water; and, after it is digested for some time, adding

100 parts water.—The resulting mixture may be sprinkled before the plough.

Various other animal substances are employed as manure—such as fish, the flesh of animals, blood, the parings of skins, and horns, hair, and woollen rags, &c.

274. VEGETABLE MANURES.—They consist of decaying, or useless vegetable matter, bog-stuff, sea-weed, &c.: and, sometimes, of the ashes derived from these substances. The kind of manure, which the various plants may be expected to produce, can easily be learned, from what I have already said [257], when speaking of their constituents.—It must, however, be borne in mind that [23] the same plant may, in different circumstances, contain variable quantities of its inorganic elements.

1,000 parts, peat, may be considered to consist of—

Carbon,	580.90
Hydrogen,	59.30
Oxygen, and nitrogen,	313.70
Sulphates of potash, soda, and magnesia,	6.73
Sulphate of lime,	10.75
Phosphate of lime,	0.92
Carbonate of lime,	8.76
Siliceous earth,	11.15
Alumina,	3.07
Oxide of iron,	4.72

1000.00

The sea-weed, found on our coasts, contains, in 100 parts, about 77.97 water, 16.57 organic matter, and 5.46 ashes.

275. MINERAL MANURES. One of the most important of these, is *lime*. It is injurious in the caustic state; but it soon loses its causticity, by decomposing animal or vegetable matter, and uniting with the carbonic acid, formed from their elements.—In this way, it breaks up their fibres, and facilitates their decomposition. Magnesia, remains caustic much longer than lime: and, hence, unless the land is rich, or contains a considerable quantity of organic matter—which affords a greater facility of obtaining carbonic acid—it is very mischievous.

276. Quick lime is useful, when a salt of iron is present. If, for example, it is added to a soil that is injured by sulphate of iron, the results are sulphate of lime, and oxide of iron—which combining with the oxygen of the atmosphere, will form peroxide, a harmless substance. Protoxide is pernicious, on account of its affinity for oxygen: and, hence, red earth—which contains it in large quantities—should be brought to the surface, that it may be peroxidated as soon as possible. A similar affinity for oxygen, renders mould, which is capable of imparting a colour to water, hurtful to plants.

Carbonate of lime may be advantageous in bogs, by removing the acids which prevent decomposition.

277. *Gypsum*, assists the growth of grasses, by fixing ammonia—carbonate of lime, and soluble sulphate of ammonia being formed. Since it is decomposed but slowly, it will last for a long time. Water is necessary for its decomposition, and for conveyance of the ammoniacal salt to the plant.—Dry fields, therefore, are but little improved by gypsum. It absorbs the ammonia evolved by night-soil, and in stables: and destroys the disagreeable smell. 100 lbs. gypsum, fixes as much ammonia, as would be derived from 6,880 lbs. of the urine of horses. If the ammonia, produced in stables, is not fixed, it will form nitric acid: which will gradually act upon the walls. This injurious action is, in Germany, termed “salpeterfrass.”

278. Sulphuric acid, added to a calcareous soil, produces gypsum.—100 parts, by weight, oil of vitriol, will afford nearly 142 parts sulphate of lime. The acid should be diluted with about eight, or ten, times its weight of water.

279. If a soil contains too much calcareous matter, it will be improved by sand.

280. There are many other kinds of manure: but, generally speaking, the reason, and amount, of their utility, may easily be inferred, from what I have already said of those chemical compounds, which are of any importance.

CHAPTER IX.

CHEMICAL ANALYSIS.

Nature, &c., of the Process, 1.—Qualitative Analysis of Water, 2.—Quantitative Analysis, 17.—Qualitative Analysis of Organic Substances, 49.—Quantitative Analysis, 55.—Analysis of a Soil, 68.—Organic Constituents of the Soil, 72.—Constituents of the Soil, which are soluble in Water, 79.—Constituents, which are soluble, in dilute hydrochloric acid, 86.—Constituents, which are insoluble, in water, and dilute acids, 90.—Constituents which are insoluble in water, and acids, 91.

1. NATURE OF THE PROCESS.—Chemical analysis* is of two kinds—the *qualitative*, and the *quantitative*. By the former, the *nature* of the constituents, contained in the body to be examined, is ascertained; and, by the latter, their *relative amounts*. In making an analysis, the operator should avail himself of every means, that suggest themselves, for securing delicacy, and exactness. Habits of neatness, and care, and a certain amount of skill in manipulation, are required in all experimental researches—but, most particularly, in those which have analysis, for their object. The strictest conscientiousness, in detailing particulars, is indispensably necessary:—without it, analysis is worse than useless. No person need be ashamed, that his results are a little more, or a little less, than, theoretically, they should be. Indeed, their *perfect* correspondence with what might be expected, is no proof of their real accuracy: for, looking to our, at best, imperfect resources, they cannot be mathematically exact. Whatever incorrectness, therefore, is found in them, should be candidly stated, if inconsiderable; but, if considerable, the analysis should be repeated. An inaccuracy should never be divided among the several items; since, besides other evils, this renders a verification impossible. An analysis, in which there is a defect, is more likely to be correct, than one in which there is an excess. Several experiments should be made: and the more nearly they agree, the more they are to be depended on. The average and, at least, the highest and lowest of the results, carefully obtained, should be mentioned. The different parts of the analysis should be made, as far as practicable, to check each other. Sometimes, it will be found possible to ascertain, with more or less of probability, the element, in which a loss has occurred:—as, for example, when, the deficiency being added to some particular element, the results

* *Ana*, severally; and *luo*, I set free. *Gr*.

will all be in atomic proportions. It is scarcely possible to state, in general terms, what extent of error may be considered allowable; since it depends on circumstances. Thus, in determining the amount of chlorine, a loss greater than one part in 1,000 must not be tolerated; while, in estimating strontia, by means of sulphuric acid, a loss, ten times as great, should not be considered unreasonable.

The subject is so extensive that I can direct attention to only a few general principles. These, however, along with what I have said, in treating of the different elements, and their compounds, will enable the student to pursue many interesting, and important researches particularly with reference to agriculture.

2. **QUALITATIVE ANALYSIS OF WATER.**—*Carbonic acid.* If, on adding lime water, to a portion which has been recently collected, and kept in a well-stopped bottle, a precipitate is thrown down, and is redissolved by adding more of the water, it contains free carbonic acid [inorg. chem. 270].

3 *Sulphuretted hydrogen.*—It will be detected by the smell: and will be rendered still more evident, on adding acetate of lead. If either sulphuretted hydrogen, or an alkaline sulphuret, is present, there will be a black precipitate or, at least, the water will be darkened [inorg. chem. 549].—Long continued contact, with the cork, may change sulphates into sulphurets: from which sulphuretted hydrogen will then be evolved, by the free carbonic acid present.

4. *Sulphuric acid.*—If, after acidifying the water, with a little hydrochloric acid, and gently warming it, a white precipitate is thrown down, by chloride of barium, sulphuric acid is present [inorg. chem. 309].

5. *Chlorine.*—If, after acidifying with a little nitric acid, and warming, nitrate of silver throws down a curdy precipitate, or causes turbidity, chlorine is present [inorg. chem. 333].

6. *Nitric acid.*—It will be detected, by evaporating a large quantity of the water to dryness, dissolving the residue in water, adding sulphuric acid and, then, protosulphate of iron [inorg. chem. 243].

7. *Iodine.*—When four or five gallons are evaporated to a very small quantity, iodine may be detected, by means of starch [inorg. chem. 363].

8. *Bromine.*—The presence of this substance may be ascertained, with chlorine water, and ether [inorg. chem. 367].

9. *Fluorine.*—Several gallons are evaporated, to dryness; and, the residue being dissolved in hydrochloric acid, ammonia is added to the solution. The precipitate obtained, is heated with sulphuric acid, in a platinum crucible covered with a glass plate.—Fluorine will then, if present, be indicated by the latter [inorg. chem. 372].

10. *Lime*, is detected with oxalate of ammonia [inorg. chem. 468].

11. *Carbonate of lime* dissolved in carbonic acid, will render the water cloudy when it is boiled, carbonic acid being evolved [inorg. chem. 270].

12. *Magnesia*. After separating the oxalate of lime [10] by filtration, and concentrating the filtered liquor by evaporation, it will be seen if magnesia is present, by adding phosphate of soda and ammonia [inorg. chem. 558].

13. *Iron*. If, on adding to some of the water, a few drops of lime water, and some tincture of galls, a dark precipitate is produced, iron is present [inorg. chem. 538].—It will be necessary to test for iron before boiling: as it is, most frequently, contained in water as a carbonate. If it is found after boiling, it must have been in combination with some other acid.

14. *Potash*. The iron, contained in some of the water, being brought to the state of peroxide [inorg. chem. 538], carbonate of ammonia is added: and, the resulting precipitate being removed, the filtered liquor is evaporated to dryness, and ignited. The residue is dissolved in water, and a solution of barytes is added, as long as it causes any precipitate. The liquor, being then boiled, is filtered and, sulphuric acid being added, to throw down the excess of barytes, refiltered. After this, it is evaporated to dryness, and the residue is dissolved in alcohol.—If, on igniting some of the alcoholic solution, the flame has a violet tinge, potash, but not soda, is present: and if, on mixing it with chloride of platinum, a yellow precipitate is at once formed, the presence of potash becomes still more evident [inorg. chem. 623].

15. *Soda*. If, when the alcoholic solution is ignited, the flame is yellow, soda is present; and it may be precipitated, by antimoniate of potash [inorg. chem. 652].—If it has been previously ascertained, that there is no magnesia, it is not necessary to add the barytic water, in looking for the potash, and soda.

16. *Ammonia*. If, a few drops of hydrochloric acid being previously added, a large quantity of the water, is evaporated to dryness by a gentle heat, caustic potash, or hydrate of lime, will show whether, or not, ammonia is present [inorg. chem. 254].

If it contains other substances, their quantity must be small: and they may be discovered in the subsequent quantitative analysis.

17. QUANTITATIVE ANALYSIS OF WATER.—*Specific gravity*. It is proper to ascertain this; which may be found, by means of the specific gravity bottle [hyd. 55], the temperature being 60°.

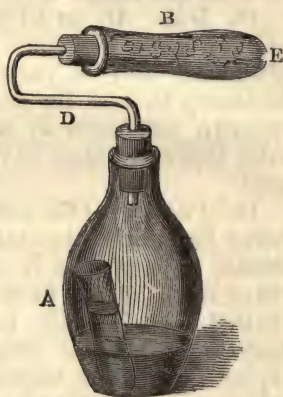
18. *Carbonic acid*.—A known quantity of the water is placed, at the spring, in well-stopped bottles, along with some chloride of calcium and ammonia—quite free from carbonic acid. This will cause carbonate of lime to be thrown down. $\text{CaCl} + \text{NH}_4\text{O} + \text{CO}_2 = (\text{CO}_2 + \text{CaO}) + \text{NH}_4\text{Cl}$. The precipitates are collected and placed in a small thin bottomed flask A, fig. 346, which contains water and hydrochloric acid—in a small test tube: and has been fitted with a cork, in which is inserted a bent tube D, that connects it with the apparatus B—nearly filled with fused chloride of calcium, in fragments. When the weight of the whole apparatus has been ascertained, the flask A is so inclined, that small quantities at a time, of hydrochloric acid may fall upon the carbonate; and, as soon as effervescence ceases, the flask is placed in boiling water, to expel the carbonic acid—which passes off at E. The aqueous vapour, which leaves the flask, is intercepted by the chloride of calcium in B; and the atmospheric air, which enters, as the apparatus cools, causes the interior to be, as it was, at the commencement.—The difference of weight, therefore, before, and after, the process, will indicate how much carbonic acid has been evolved, by the carbonate.

This apparatus is well suited to the analysis of limestone, marl, &c.

19. To ascertain how much carbonic acid, is in combination with the fixed alkalis.—About 5,000 grains of the water are boiled for some time, and filtered:—hot water is used in washing; and what passes through the filter is added to the rest of the clear liquor. The latter is then divided into two portions: nitric acid is added to one, and its chlorine being precipitated with nitrate of silver, the resulting chloride is dried, &c., and weighed: the other having been acidulated, with hydrochloric acid, the chlorine it then contains is precipitated, dried, &c., and weighed.—The larger amount of chlorine, in the latter case, is due to the carbonic acid which, having been combined with fixed alkalis, was driven off by the hydrochloric acid. 100 grains excess of chloride, are equivalent to 15·34 grains carbonic acid.

20. *Sulphuretted hydrogen*.—Some bottles, in which a small quantity of arsenious acid dissolved in hydrochloric acid has been placed, are filled, at the spring, with a known quantity of

FIG. 346.



the water; and the sulphuret of arsenic (AsS_3), that will be thrown down, is washed, dried, at 212° , and weighed. It contains 39.05 per cent. sulphur; and the quantity of sulphuretted hydrogen, may easily be deduced from this.

21. *Solid ingredients.* To ascertain what amount of these is contained in the water, 1,000 grains of it, are evaporated, to dryness, in a platinum crucible, placed in a water bath: and the residue is dried, at various temperatures, and weighed—that degree, above which, no further diminution occurs, being noted. This will give an approximation to the quantity of solid matter.—It will, however, be only an approximation; since ammoniacal salts may have been set free; and earthy chlorides, may have been decomposed, at a temperature higher than 212° —on account of water having been removed.

22. *Sulphuric acid.* About 8,000 grains of the water are acidified with hydrochloric acid, and precipitated with chloride of barium. The resulting sulphate of barytes, being allowed to rest for twenty-four hours, is filtered, dried, and heated to redness, in contact with the air—without which it would be changed into sulphuret of barium. It contains 34.37 per cent. sulphuric acid.

23. *Nitric acid.*—About a gallon of the water is evaporated, down to a few ounces, and filtered; and the clear liquor is macerated, with enough of sulphate of silver to change the chlorides, iodides, and bromides, into sulphates. The resulting precipitate is removed, and the clear liquor, having been rendered alkaline with carbonate of soda, is concentrated in a water bath; then mixed, in a tubulated retort, with more than enough pure sulphuric acid—previously boiled—to change all the ingredients present, into bisulphates; and, afterwards heated, in a sand bath. The vapours which pass over are to be conducted into a glass receiver, containing a solution of hydrate of barytes—the distillation being stopped, as soon as vapours of sulphuric acid begin to rise. The fluid in the receiver is evaporated in a water bath, almost to dryness; and the residue is exposed to the air, for about twelve hours—to change the excess of hydrate into carbonate of barytes, which is removed, by filtration. And, lest any carbonate should be dissolved, the evaporation almost to dryness, and the filtration, should be repeated. When all the carbonate has been taken away, dilute sulphuric acid is added, and the resulting sulphate of barytes is washed—at first, with boiling distilled water—dried, and ignited. It contains 65.63 per cent. barytes, which corresponds with 46.4, nitric acid.

24. *Phosphoric acid.*—About 80 lbs. of the water are evaporated to something more than two, and filtered—the washings being added to the mother liquor. Both the “mother liquor,”

and the "precipitate," will be required for several purposes:—they must, therefore, be accurately weighed, that the quantity of each, corresponding to a given amount of the water, may be easily known. One-half of the precipitate is then dissolved, in hydrochloric acid, and precipitated with acetate of lead; and the resulting phosphate of lead—which is not of an invariable composition—being collected on a filter, washed, dried, ignited, and weighed, is dissolved in as little nitric acid as possible, and precipitated with sulphuric acid—alcohol being added, to prevent any of the sulphate of lead from being dissolved. The sulphate is to be collected on a filter, washed with dilute alcohol, ignited, and weighed. It contains 73·64 per cent. oxide of lead; which, being deducted from the weight of the phosphate of lead, gives that of the phosphoric acid.

25. *Chlorine, iodine, and bromine.*—About 15,000 grains of the "mother liquor" [24] are evaporated to dryness, along with some carbonate of soda: and the residue is digested, several times, with alcohol. The alcoholic extract is evaporated to dryness, and the residue, having been gently ignited in a platinum crucible—to destroy any organic matter present—is dissolved in water, and filtered. The clear liquor is carefully neutralized with hydrochloric acid, and precipitated with protochloride of palladium. The protoiodide of palladium, which is thrown down, after being allowed to rest for twelve hours, is separated by filtration, washed with warm water, and dried at a temperature below 212° or, which is better, with sulphuric acid, *in vacuo*. It contains 70·53 per cent. iodine.

26. The fluid, from which the protoiodide of palladium has been removed, is saturated with sulphuretted hydrogen—to throw down the excess of palladium; then filtered, boiled with nitric acid, again filtered—if necessary, and precipitated with nitrate of silver. The resulting precipitate—which contains all the chlorine, and bromine, as chloride, and bromide of silver—having been washed, dried, fused, and weighed, is introduced into a bulbed tube of hard glass, of a known weight: and, the silver salts being kept in a state of fusion, and agitated occasionally, a current of chlorine—dried by transmission through fused chloride of calcium—is passed into them. When the process has been continued for about half an hour, the tube is allowed to cool, and being freed from chlorine, by a current of atmospheric air, is weighed. After this, chlorine is again passed into the salts, in a state of fusion, and the excess is expelled by atmospheric air, as before.—If the weight has not been altered, by the second application of chlorine, enough of that substance has been employed, and the difference between the weights, before and after it was transmitted, arises

from the bromine having been displaced, by chlorine. For every grain, diminution of weight, there were 4.22 grains of bromide, in the mixed silver salt; and the bromide contained 42.56 per cent. bromine. The weight of the mixed chloride and bromide, minus the weight of the bromide is the weight of the chloride; and the chloride contains 24.74 percent. chlorine.

27. *Fluorine*.—If this is present, it must be, in very small quantity. I shall, hereafter, point out the mode of determining its weight, when the latter is too large to be neglected.

28. *Silex, iron, lime, magnesia, and alumina*.—About 12,000 grains of the water are placed, along with some nitric acid, in a large glass flask, and the carbonic acid is expelled by heat. It is then evaporated to dryness, in a porcelain basin, and a water bath: and the residue, having been heated in a sand bath, until the moisture has been completely expelled, is digested with hydrochloric acid, and a gentle heat is applied:—water is added, occasionally, and the mixture is kept stirred. The silicic acid, which has been rendered insoluble by drying [inorg. chem. 377], is washed with hot water, dried, ignited, and weighed—while hot, or after it has been cooled, with sulphuric acid under an exhausted receiver.

29. Ammonia being added to the liquor, from which the silex has been taken, hydrated peroxide of iron is thrown down: and, the mixture being heated nearly to ebullition, the peroxide is removed, by filtration, washed, with hot water, dried, and ignited.—If it is not well washed, some of the iron will be volatilized, as perchloride. Should it be ignited, with the filter [inorg. chem. 54], some of it may be reduced—particularly when there is not free access of air; but moistening with nitric acid, and reheating, will re-peroxidate it.

30. If the precipitated peroxide of iron is not of a fine brownish red colour, it arises from the presence of alumina, or phosphoric acid. In such a case, after being well washed, it is dissolved in hydrochloric acid; and caustic potash, in slight excess, is added to the solution. The resulting precipitate is removed from the alkaline liquor—which contains any alumina present—by filtration; and, being washed, is redissolved in hydrochloric acid. Ammonia, in excess, is added to the solution—to neutralize the free acid, then hydrosulphuret of ammonia, and a gentle heat is applied. The vessel is covered with a glass plate, and left at rest, in a moderately warm place, until the liquor acquires a yellow tint, if it has not that colour already. The precipitated sulphuret of iron is removed, by filtration, and is washed continuously, with water containing a little hydrosulphuret of ammonia. If the funnel is left uncovered during the filtration and washing, the iron will be oxidated, and a soluble protosulphate will be formed:—should this take place, reprecipi-

tation will be caused by the hydrosulphuret of ammonia, in the receiver underneath. When the sulphuret of iron is well washed, it is transferred, along with the filter, to a glass jar, and redissolved by hydrochloric acid, the sulphuretted hydrogen being driven off, by heat. The solution is filtered into a flask, and well washed through the filter: after which, the iron is peroxidated with nitric acid, precipitated with ammonia, and treated as I have already described [29].

31. *Alumina*.—The alkaline solution containing it [30], is moderately diluted; and a rather large quantity of sal-ammoniac being added, and then ammonia in excess, heat is applied; after which, the precipitate is removed by filtration, washed, dried, ignited, and weighed.—A gentle heat must be employed at first, and the crucible must be kept covered: otherwise, a portion of the gelatinous hydrate will be thrown out. All the water is driven off, by the high temperature, and the residue is pure alumina.

32. *Lime*.—When the iron, and alumina, have been precipitated, by ammonia [30], and removed, ammonia is added to the washings, until its smell is perceptible: and, then, oxalate of ammonia, to throw down the lime. Previous to filtration, the vessel is covered, and left in a warm place, until the precipitate subsides:—without this precaution, it would pass through the filter. Should any of the oxalate adhere firmly to the glass, it must be dissolved off by hydrochloric acid; and, being precipitated with ammonia, must be thrown on the filter, along with the rest. The oxalate having been well washed, and dried, is ignited: and the ignition is continued, for about a quarter of an hour after the bottom of the crucible has begun to glow:—it is then cooled, and weighed. If too great heat has been applied, the ignited precipitate, on being moistened, will change turmeric paper to brown—on account of the presence of caustic lime. When this occurs, the turmeric paper must be rinsed into the crucible—that nothing may be lost; and, a bit of carbonate of ammonia being added, the precipitate is evaporated to dryness, in a water bath, and again weighed.—The residual carbonate contains 56 per cent. lime.

33. *Magnesia*.—After the lime has been removed, phosphate of soda, in excess, is added to the clear liquor—which is to be stirred with a glass rod, but without touching the sides [inorg. chem. 558]. At the end of twelve hours, the precipitate is thrown on a filter, and washed, with a mixture containing one part solution of sal-ammoniac, and seven parts water, until a drop of the washings leaves no residue, when evaporated on platinum. As soon as the precipitate is dry, it is ignited in a platinum crucible, a gentle heat being, at first, applied.—The resulting pyrophosphate ($\text{PO}_5 + 2\text{MgO}$) contains 36.64 per cent. magnesia.

34. The iron, lime, and magnesia, which were thrown down, by boiling—and, therefore, were dissolved by free carbonic acid—may be ascertained, by boiling 10,000 grains of the water, in a glass flask, for about an hour: distilled water being occasionally added, to prevent the sulphate of lime from being precipitated. The precipitate is then removed by filtration, dissolved in dilute hydrochloric acid, and heated with some nitric acid. The iron, &c., which it contains, may be thrown down, as usual [29, 32, and 33].

35. *Strontia*.—The remainder of “the precipitate” [24] is dissolved in hydrochloric acid: then ammonia in excess, and hydrosulphuret of ammonia, are added to the solution. The precipitate—containing sulphurets of iron, manganese, and alumina—being removed by filtration, a solution of gypsum is added to the clear liquor, to throw down sulphate of strontia. As this is slightly soluble in water, but is nearly insoluble in alcohol and spirits of wine, alcohol is poured into the liquor, and, after the precipitate is placed in the filter, it is washed with spirits of wine. When dried, and ignited, it contains 56.36 per cent. strontia.

36. *Manganese*.—The precipitate, containing the iron, manganese, and alumina [35], being well washed, is dissolved in hydrochloric acid, and heated with nitric acid—to peroxidate the iron [inorg. chem. 330]. Caustic potash, which throws down only the iron, and manganese, is added in excess: and the mixed precipitate is filtered, washed, and dissolved in hydrochloric acid. An extremely dilute water of ammonia is dropped into the solution, very gradually, until the fluid acquires a brown red colour, on account of a slight precipitation of iron.—If the latter is not redissolved, by heat, enough ammonia has been added: but, if the fluid is rendered colourless by it, too much ammonia has been used and, the excess being neutralized by hydrochloric acid, ammonia must be again poured in with more caution than before. When the proper quantity has been employed, a perfectly neutral solution of succinate of ammonia is added, as long as any precipitate is thrown down, and a gentle heat is applied. As soon as the fluid cools, the precipitate is removed: and, the clear liquor being placed in a capacious flask, and heated to 212° , carbonate of soda, in excess, is added, until the escaping vapour ceases to render turmeric paper brown. The resulting precipitate is filtered, dried, and changed from carbonate of manganese to manganoso-manganic oxide (Mn_2O_4)—by heating to redness, with access of air. It contains 72.1 per cent. metallic manganese.

37. *Fixed alkalies*.—About 10,000 grains of the water being evaporated to 6,000, they are mixed with excess of barytic water, and filtered. Carbonate of ammonia is added to the

washings—to remove the lime and excess of barytes, and the filtration is repeated. The washings are evaporated to dryness, ignited, and redissolved in hydrochloric acid—to bring the alkalies to the state of chlorides: then evaporated, again, to dryness, ignited, and weighed. The residue is dissolved in water, and precipitated with an aqueous solution of bichloride of platinum, in excess; and the mixture, having been evaporated to dryness in a water bath, is heated with spirits of wine, containing from 76 to 80 per cent. alcohol. After some hours, the potassio-chloride of platinum is removed from the solution of sodio-chloride, by filtration.—If the clear liquor is not of a deep yellow colour, enough bichloride of platinum has not been used. The potassio-chloride is washed on a filter, with spirits of wine: then dried, at 212° , and weighed. It contains 16.01 per cent. potassium: and 30.52 per cent. chloride of potassium. The chloride of potassium, deducted from the mixed chlorides of potassium and sodium, will give the chloride of sodium.

38. If the alkalies, in the water, are combined with phosphoric acid, before converting them into chlorides, the ignited mass is redissolved in water, and precipitated with neutral nitrate of silver—to take away the phosphoric acid. The excess of nitrate is removed, with hydrochloric acid.

39. If they are in combination with boracic acid, the ignited mass is digested, in a platinum crucible, with three or four parts pulverized fluor spar, and concentrated sulphuric acid—heat being applied, as long as fumes are given off. This changes the boracic acid into gaseous fluoride of boron, and the alkalies into sulphates—which may be changed into chlorides.

40. *Ammonia*.—A large quantity of the water is to be slightly acidified with hydrochloric acid, and concentrated by evaporation. The concentrated liquor is mixed in a tubulated retort, with a large quantity of caustic soda, and boiled for a long time—the vapours being condensed in a receiver, containing dilute hydrochloric acid, and surrounded with ice, or cold water. When the fluid has boiled down to two or three ounces, bichloride of platinum is added to what has distilled over, and the mixture is evaporated to dryness, in a porcelain vessel. The residue, after being lixiviated in a mixture consisting of two volumes of alcohol, and one of ether—in which the ammonio-chloride is perfectly insoluble—is dried at 212° , and then weighed. It contains 8.07 per cent. ammonium, which corresponds with 7.622 ammonia.

41. *Lithia*, if its presence is suspected.—Ten, or twelve, gallons of the water are evaporated down to about a pint, and then—the precipitate which has formed having been removed—to dryness, along with carbonate of soda. The residue, after being heated with boiling water, is filtered, and the clear liquor

is mixed with phosphate of soda, and evaporated to dryness. On adding water—as there is an excess of phosphate of soda—the resulting phosphate of soda and lithia, will be quite insoluble, and may be removed. This double phosphate consists of an atom of phosphoric acid, combined with three atoms of fixed base: it dissolves in 1,400 parts water, at 59° , and 951 parts at 212° . But soda, and lithia, being isomorphous, more, or less, of the base may be lithia:—its constitution, therefore, is variable. Hence, after being dissolved, its phosphoric acid is removed with nitrate of silver; and the excess of nitrate, with hydrochloric acid. The soda and lithia are then changed to chlorides: the liquor containing them is evaporated to dryness: and the chloride of lithium (LCD) is separated from the chloride of sodium, by a mixture containing equal parts absolute alcohol and ether—which dissolves the chloride of lithium, and but a trace of the chloride of sodium. The chloride contains 15.59 per cent. lithium: which is equivalent to 34.63, lithia.

42. *Organic matter*.—The total amount of this, contained in the water, may be ascertained, by boiling down a large and known quantity; evaporating it to dryness, with carbonate of ammonia; drying the residue, at 284° , and weighing; then igniting, till the dark colour, at first produced, has disappeared, and again weighing.—The difference between the weights, will indicate the amount of organic matter.

When I describe the analysis of soils, I shall point out the methods of estimating the various organic substances, which are likely to be found in water, or soils.

43. *Results of analysis*.—In arranging these, the date at which the water was collected, is to be stated: also, the precise part of the river, &c.: the temperature of the atmosphere, and of the water; the specific gravity of the latter; the substances detected, during the “qualitative,” and those examined during the quantitative analysis—the amount of water employed in looking for each, and the per centage obtained being specified. Thus, let two experiments have been made, to determine the amount of chlorine, 6,000 grains of water being employed, in one, and 8,000 in another. Let the chloride of silver, obtained in the former case be 0.383 grains, and in the latter, 0.523 grains:—the noting may be as follows—

	Quantity of water.	Chloride of silver.	Per centage of chlorine.
I. . . .	6,000	0.383	0.001579
II. . . .	8,000	0.523	0.001617

Mean, 0.001598

44. The salts, that are thrown down by boiling, may be considered as carbonates, kept in solution by carbonic acid.

45. The sulphuric acid may be looked upon, as combined with lime; what is left, with potash; and, if any still remains, with soda.

46. The iodine, and bromine, as combined with magnesium.

47. The chlorine, as united with the remainder of the magnesium, and, with sodium.

48. One part of the analysis, may be checked, by another.—Thus, the amount of the fixed constituents, should be equal to the sum of the several ingredients.

49. **QUALITATIVE ANALYSIS OF ORGANIC SUBSTANCES.**—The substance to be analyzed, should be as pure as possible. The amounts of the organic, and the inorganic matter, should be ascertained, by drying it in a water bath—or, in vacuo, with sulphuric acid—and weighing: then exposing to a high heat, and again weighing.—The difference of the weights will indicate the amount of organic matter driven off.

50. *Nitrogen.*—If, during the ignition, a smell resembling that of burnt feathers is perceptible, nitrogen is present. When the quantity of that element is very small, it may be detected, by putting a bit of potassium at the bottom of a test tube, and placing upon it some of the substance to be examined: then heating to a dark redness, with a lamp. The residue—after it has cooled—being dissolved, with four or five drops of distilled water, the solution is poured off, and added to a liquid, containing magnetic oxide of iron. If any nitrogen is present, a dirty green precipitate—which immediately changes to blue, on adding a drop of hydrochloric acid—is thrown down. This test depends on the fact, that cyanide of potassium is formed, when an organic substance, containing very little nitrogen, is calcined at a red heat, with excess of potassium—atmospheric air being excluded. The experiment will not, however, be successful, if the substance, under examination, is accidentally mixed with a nitrate, or with an ammoniacal salt.

51. *Sulphur.*—To ascertain if the organic body contains sulphur.—Some of it is boiled, almost to dryness, with a strong solution of caustic potash; and, the residue being dissolved in water, the solution is poured into a bottle A, fig. 347. The cork B, having the funnel PH fixed in it, is then inserted, but not air-tight, into the neck of A, a slip of paper D, which has been well moistened with a solution of acetate of lead, and then touched with a solution of carbonate of ammonia, having been previously attached to the cork. When hydrochloric acid is introduced, gradually, through the funnel, if sulphur is present, the slip of paper will turn brown—sulphuretted hydrogen being evolved.

52. *Phosphorus.*—Solid substances are mixed with carbonate

FIG. 347.



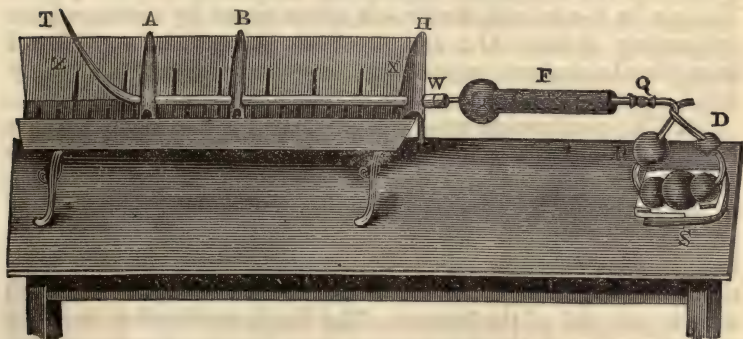
of soda, and nitrate of potash : and nitrate of potash, heated to fusion in a porcelain crucible is then thrown into the mixture. The result, when cold, is dissolved in water : and, the solution being acidified, with hydrochloric acid, one or two drops of perchloride of iron, and then an excess of acetate of potash, are added.—If phosphoric acid is present, in any form or combination whatever, it is thrown down as a white, flocculent, gelatinous perphosphate of iron ($3\text{PO}_5 + 2\text{Fe}_2\text{O}_3 + 3\text{HO}$) ; and the fluid will be colourless, unless too much perchloride has been employed—in which case it will be red.

53. If the organic substance under examination is a fluid, it is treated with a mixture of nitric acid and chlorate of potash—at first without, but afterwards, with application of heat ; and, most of the excess of nitric acid being removed, the phosphoric acid is precipitated, as before, with the perchloride of iron, and acetate of potash.

54. *Chlorine*.—A portion of the organic body is ignited, with caustic potash ; and the residue being dissolved, nitrate of silver is added to the solution. Chlorine is precipitated, as chloride of silver [inorg. chem. 333]. Iodine, and bromine, may be detected, at the same time, by methods which will easily suggest themselves, from what I have said of these substances [inorg. chem. 363 and 367].

55. QUANTITATIVE ANALYSIS. To ascertain the amount of the different elements, driven off by heat, when the substance has been found *not to contain nitrogen*.—A known weight of it, having been finely pulverized, is well dried, in a water bath—or *in vacuo*, along with sulphuric acid. It is then, intimately mixed, with perfectly dry, and warm, oxide of copper [inorg. chem. 493], and placed in a “combustion tube” TW, fig. 348.

FIG. 348.



The latter—which should be very clean and dry—consists of a glass which fuses with difficulty :—the end T, is hermetically

sealed: and the aperture at W, which is perfectly round, is thickened at the edges with the blow-pipe [inorg. chem. 114]. Some pure oxide of copper is introduced first: then a mixture of oxide and the substance to be examined: next, rinsings of oxide—used for cleaning out the mortar in which the mixture was made, so as to leave none of the substance adhering to it; afterwards pure oxide; and, in the vacant space outside, a piece of amianthus, to abstract the moisture generated, and prevent its breaking the glass, before it has been expelled by heat—also, to keep the particles of oxide from being, by any possibility, projected from the tube, as the heat approaches them. The arrangement should be complete, before the oxide is cold. An exceeding good, and perfectly dry, perforated cork, is now to be inserted into W; and the whole is shaken, by gentle taps—so as to free the pointed end, from oxide, and leave a channel, all along the upper side of the tube, that the gases may pass away, freely. The small quantity of moisture, that may have been absorbed, while the arrangements were being made, is removed, by putting the tube into a trough A, fig. 349, containing sand, the temperature of which

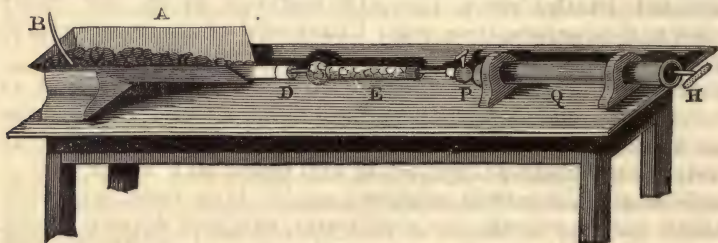


FIG. 349.

exceeds 212° , but is not sufficiently elevated, to char paper. The air in the tube is drawn out a few times, by means of the exhausting syringe Q: and the fresh air, which is admitted from the atmosphere on opening the stock-cock P, is completely dried, by the fused chloride of calcium, in the apparatus E.

56. The combustion tube is next placed in the small furnace Z, fig. 348, which is made of sheet iron.—It may be, about two feet long, four inches high, five inches wide, at the top, and three at the bottom. Small slits across the latter, form a species of grating: and upright transverse pieces, riveted to it, support the combustion tube—their upper edges being all of exactly the same height, and coincident with the lower edge of an aperture, in one end of the furnace. The fire is confined to any particular portion of the combustion tube, by movable screens A, and B. A similar screen H, protects the cork of the combustion tube from the fire, within the furnace. The air must be allowed

to pass freely, during the operation, through the grating. The smaller end of the apparatus F—which contains fused chloride of calcium, and has been previously weighed, is inserted—air-tight, in the open end of the tube TW, and is carefully connected, by means of a bit of Indian rubber tubing [inorg. chem. 94] Q, with the caustic potash apparatus D. The latter consists of a tube bent as represented, and having five bulbs blown upon it—that a large surface of potash may be exposed to the gases which will pass through it. Having been carefully weighed, it is placed on a cloth S, and is raised, at one side, by a cork, &c.—If the whole apparatus is air-tight—which is quite indispensable—a red hot coal, held near the larger side bulb P, will cause the air within it to expand, and partially escape from the apparatus: after which, on cooling, the solution of caustic potash will ascend towards it. And if, at the end of five minutes, the potash shows no tendency to assume its former position, it may be concluded that every thing is as it should be.

57. A sufficient quantity of red hot charcoal having been placed close at hand, that part of the combustion tube which is next the end T, is enclosed between two screens, and then surrounded with small pieces of lighted charcoal—so as to make it red hot, as soon as possible. One of the screens is then gradually shifted back—about an inch at a time—that new portions of the tube may be exposed to the burning fuel.

58. The aqueous vapour, and the carbonic acid, evolved by the decomposing organic substance, will be absorbed, respectively, by the chloride of calcium, and the caustic potash. The bubbles of gas should be made to pass off uniformly, and not too rapidly:—some of them, at first, will not be absorbed, since they will consist of atmospheric air, driven out of the tube. When the evolution of gas ceases, which generally occurs suddenly, the lower bulbs of the potash apparatus are laid in a horizontal line, by removing the cork, which was placed under one side: and, as soon as the potash is seen rushing towards Q, the fine point of the combustion tube is clipped off, with a pair of scissors.—This allows the atmospheric air to enter, and supply the vacuum, caused by the cooling. Suction through the potash tube, will make the residual aqueous vapour, and carbonic acid, pass into what is intended to absorb them.

59. After about half an hour, the chloride of calcium tube, and the potash apparatus, are again weighed. The increased weight of the former is due to the water: and that of the latter to the carbonic acid, absorbed. The excess of the sum of the weights of the water and carbonic acid, above the weight of the—previously determined—organic part of the substance analyzed, is due to oxygen derived from the oxide of copper; and must therefore, be deducted from the oxygen of the result.

The amount of water, is the weight of the chloride of calcium tube, *after* minus its weight *before* combustion. 11.111 per cent. of this is hydrogen: and 88.888 oxygen. The weight of the carbonic acid is the weight of the potash apparatus *after*, minus its weight *before* combustion:—27.273 of this is carbon: and 72.727 oxygen. The carbon in the substance, is the carbon of the carbonic acid: its hydrogen, the hydrogen of the water; and, since it is not supposed to contain nitrogen, phosphorus, &c., its oxygen, is the weight of its organic part, minus the sum of the weights of the carbon and hydrogen.—The per centages of carbon, hydrogen, and oxygen, may be found, from these.

60. *Nitrogen*.—The quantitative determination of this, is effected by a separate process. And, since the oxide of copper would change a portion of it into nitric oxide—which would be converted, by the potash, into nitrous acid, and retained—the quantity of carbon would appear greater than it really is. Hence, when substances, containing nitrogen are analyzed, the oxygen compounds of that element must be decomposed, before they pass out of the combustion tube. This is effected, by laying over the oxide of copper—for about four or five inches of the anterior portion of the tube—pure copper turnings: and keeping them intensely ignited, during the entire process. The nitrogen then passes off, uncombined.

61. To estimate the amount of nitrogen.—The substance is placed in the combustion tube—which may, in this case, be sealed, without being drawn to a fine point—along with the oxide of copper, and clean iron turnings. Five or six inches of bicarbonate of soda, previously placed at the sealed end of the tube, on being intensely heated, evolve carbonic acid—which expels the atmospheric air, at the commencement, and the nitrogen, at the end of the process: and the gases, that pass from the combustion tube, are transmitted into a mercurial pneumatic trough.—All the atmospheric air may be known to have been driven off, when the gas, being transmitted into a test tube, containing potash solution, and inverted over the mercury, is entirely absorbed. As soon as this is the case, a graduated jar—which has been previously filled, two-thirds, with mercury, and the remaining third, with solution of caustic potash—is, by means of a ground glass plate, inverted, and then placed in the mercury, in such a way, that the gas from the combustion tube may ascend into it. And, to complete the separation of the carbonic acid from the nitrogen, the graduated jar should be left at rest, for some time after the process is finished. The jar is then removed to a vessel of water: and the mercury, and potash, having descended through that fluid, the liquid in, and outside, of it is brought to the same level, and the nitrogen is read off. The proper corrections are made

for pressure [pneum. 42], temperature [heat 73], and the presence of aqueous vapour [heat 103]. The weight is deduced from the volume.

62. The result will, probably, be found a little too high; on account of its being very difficult to prevent some atmospheric air from remaining attached to the oxide of copper.

63. *Sulphur*.—When the organic substance contains sulphur, some of it, becoming sulphurous acid, will be absorbed by the potash—unless a tube, about six inches long, and filled with perfectly dry peroxide of lead, is interposed between the combustion, and the chloride of calcium tubes, fig. 348. Sulphate of the protoxide of lead is then formed, and detained. $\text{SO}_2 + \text{PbO}_2 = \text{SO}_3 + \text{PbO}$.

64. To ascertain the amount of sulphur.—The organic substance, having been finely pulverized, is fused in a large silver dish, with twelve times its weight of caustic potash; and then, having been mixed with about half its weight of nitre, it is heated, till the fused mass is quite white. The whole is next supersaturated with hydrochloric acid; and nitrate of barytes is added.—The sulphuric acid is estimated, from the resulting sulphate of barytes, in the way I have already described [22]. 40 per cent. of the sulphuric acid is sulphur.

65. *Phosphorus*.—When an organic substance contains phosphorus, its amount is ascertained by oxidizing with a mixture of nitric acid and chlorate of potash. The phosphoric acid is obtained, from the resulting solution: and is estimated in the usual way [24]. 43·915 per cent. of the phosphoric acid is phosphorus.

66. When the organic substance contains chlorine, subchloride of copper will be formed in the combustion tube, and will be condensed in the chloride of calcium tube—unless chromate of lead is substituted for the oxide of copper. For this purpose, more chromate of lead than will be sufficient to fill the combustion tube—which may be narrow—is heated, in a porcelain dish, until it begins to turn brown: and, being then allowed to cool below 212° , it is substituted for oxide of copper. The other arrangements remain the same—except that, the chromate not being hygrometric, the exhausting syringe [55] is not required. Chloride of lead—which remains in the combustion tube—is formed.

67. *Chlorine*.—The amount of this is determined, by igniting the organic substance, in a combustion tube, with a mixture, consisting of three parts hydrate of lime and one part hydrate of soda; then dissolving the ignited mass, in very dilute nitric acid: and precipitating the chlorine, with nitrate of silver. The chlorine is estimated, as before mentioned [26].

Bromine, Iodine, &c.—Substances, containing these are

treated in the same way; and their weights are determined, as before [25 and 26].

68. *ANALYSIS OF A SOIL*.—About one pound of what may be considered a fair average of it; and the same quantity of subsoil, lying immediately beneath, are placed in canvass bags, and labelled.—It is to be remembered, that a difference of subsoil, will cause a difference in the degree of fertility. The portion of each, which is to be used in qualitative, and quantitative, analyses, having been carefully dried in the air, and well mixed, is placed in a stoppered bottle.

69. *Specific gravity*.—This is determined, by drying some of the soil, at 212° , and introducing it into the specific gravity bottle, half filled with distilled water [hyd. 57].

70. *Sand, gravel*.—About 500 grains are well agitated with hot water, in a large flask; the whole mixture is then poured into a jar, and allowed to stand for a couple of minutes; after which the water, and the finer portion of the soil suspended in it, are poured off into another vessel. This is repeated, until nothing but sand, and gravel, are left behind. The latter is thoroughly dried, and then passed through gauze sieves, of different degrees of fineness. The separated portions are each weighed; then moistened with water, and examined with a microscope—for the purpose of learning the substances, of which they consist. If moistening them, with a few drops of hydrochloric acid, causes effervescence, *limestone* is present; if a brown colour has been imparted to the acid, *peroxide of iron*: and, if there is a smell of chlorine, *peroxide of manganese*.

The other ingredients, likely to be found, are detected by the appropriate tests.

71. *Absorbent powers*.—500 grains are exposed to the atmosphere, on a sheet of paper, for twelve hours. If the soil is good, their weight will have increased by, from seven to ten grains: if the increase has been fifteen, or twenty grains, it is an excellent indication. The same portion of the soil is next placed on a double filter, in a funnel; and water is poured on it, till drops begin to fall from the funnel. It is then covered with a glass, and allowed to stand for a couple of hours—a little water being occasionally added, until it is certain that the entire is wetted thoroughly. The filters are then removed from the funnel, and placed on a cloth, that the drops, which adhere, may be absorbed:—after this, the filter containing the soil is to be placed in one scale, and the other filter, in the other scale. The increase of weight will indicate how much moisture is retained. It is next to be spread on a plate, and exposed to the air, for a certain number of hours. The weight lost will show the *comparative* rapidity, with which it dries—and, by consequence, whether or not there is a necessity, either for drainage or irrigation. The

times, in which water evaporates from sand, clay, and peat, in the same circumstances, are as four, eleven, and seventeen.

72. **ORGANIC CONSTITUENTS OF THE SOIL.**—To ascertain the *total amount* of these.—About 150 grains are completely dried, at a temperature not higher than between 250° and 300° , and then weighed. They are next ignited, until all blackness disappears; and, afterwards, having been moistened with carbonate of ammonia, are dried, again ignited, and weighed. The difference between the two weights, will indicate the amount of organic matter. The result will not, however, be quite accurate; for, certain soils do not lose all their water, except at a temperature which is sufficient to decompose the organic matter:—also, carbonic acid, nitric acid, and ammonia, may have been driven off.

73. When the soil is treated with water, combinations of the fixed alkalis, ammonia, lime, and magnesia, with formic, acetic, humic, crenic, apocrenic, and carbonic acids, are among the substances obtained from it. Alkaline solutions will then extract compounds, which may be precipitated with acids; and which, from whatever soil they may be derived, exhibit a great uniformity of constitution, and very strikingly resemble the last products [256] of animal, and vegetable decomposition. The crenic and apocrenic acids are always found, in the soil, as salts of ammonia, potash, and soda—combined with lime, magnesia, and oxide of iron: and they are insulated with extreme difficulty.

74. *Humic acid.*—500 grains of the soil are digested, for several hours, at a temperature not exceeding 200° , with a solution of carbonate of soda: and, then filtered:—if the filtered liquor is muddy, it is concentrated, and again filtered. The clear liquor being mixed with hydrochloric acid, in slight excess, humic acid precipitates, in the form of light brown flakes—which are to be filtered, washed, dried, and weighed.

75. *Humous acid* or *humine*, &c.—About 500 grains are digested, with caustic potash, for some hours, in a porcelain vessel; the alkaline fluid is then diluted with water, and the undissolved portion is washed in a filter. Hydrochloric acid, added to the clear liquor, precipitates all the humous, in the form of humic acid.—The difference between its weight and that of the humic acid, obtained in the experiment, with carbonate of soda [74], indicates the amount of humous acid. And the sum of the weights of the humous and humic acid, deducted from the total weight of the organic matter, gives the weight of the organic elements which do not belong to the humic group.

76. *Waxy, and resinous substances.*—About 2,000 grains are digested, with strong alcohol; the result is filtered, and the

clear liquor is precipitated, by diluting the alcoholic solution, with water.

77. *Nitrogen*.—The amount of this may be determined, by the methods I have already described [61, &c.]

78. *Carbonic acid*, &c.—100 grains of the soil are placed in a counterpoised bottle [18], containing hydrochloric acid. The weight lost, will indicate the quantity of carbonic acid, which has been driven off. The *ammonia*, if considerable in quantity, may be determined as described [40].

79. **CONSTITUENTS OF THE SOIL, WHICH ARE SOLUBLE IN WATER.**—About 15,000 grains of the dried earth, is covered, with water, in a porcelain capsule, and kept boiling for about an hour—being stirred occasionally. The liquid is then strained through a moistened filter; after which, more water is poured on, and the process is repeated until a drop of what passes through leaves scarcely any residue, when evaporated.—If gypsum is present, the washing is tedious. The entire of the solution is now weighed, and divided into four parts—one of which is twice as large, as each of the others. I shall call the three smaller A, B, and C; the larger D.

80. *Total amount of soluble ingredients.*—To ascertain this, part A is evaporated, to dryness: then ignited, for some time, in a platinum crucible, and weighed.

81. *Chlorine*, &c.—This is precipitated from part B by nitrate of silver, nitric acid being previously added: and the chlorine, &c., are deduced from the chloride [25]. When the silver salts have been removed, hydrochloric acid is added to the clear liquor, and then nitrate of barytes. The amount of the *sulphuric acid* may be found, from the resulting sulphate of barytes [22], which should be extremely well washed.

82. *Carbonic acid*.—The amount in C, is ascertained, by evaporating it to a very small quantity: then placing it, along with hydrochloric acid, in the usual apparatus [18].

83. The carbonic acid, in the insoluble carbonates, may be determined, by drying a portion of the soil, from which the aqueous solution [79] has been obtained, on a filter, and mixing it well: then, using some of it, as I have described [18].

84. *Silex*.—Part D is evaporated, to dryness, in a water bath, with hydrochloric acid, in excess—being kept stirred all the time; and the residue is dried, in a sand bath; then digested, with hydrochloric acid—a moderate heat being applied. The silex—which remains undissolved—is washed on a filter with hot water; and, after being well dried is estimated [28].

85. The liquid, from which the silex has been separated, is divided into three equal portions:—one of them is used in determining the amounts of potash, and soda, in the way I have mentioned [37]. The phosphoric acid is determined, by means

of another [24]; the alumina [31,] lime [32], magnesia [33], and manganese [36], by means of the third.

86. **CONSTITUENTS OF THE SOIL, WHICH ARE SOLUBLE IN DILUTE HYDROCHLORIC ACID.**—About 250 grains [79] of what has been used, for discovering the ingredients soluble in water, is agitated, with some water, in a glass flask, so as to form a pasty mass. Heat being then applied, hydrochloric acid, in excess, is gradually added. The mixture, after this, is kept near the boiling point, for about two hours—the flask being frequently shaken; and then being thrown upon a moist filter, is extremely well washed. The resulting clear liquor is evaporated to dryness, with some nitric acid; the residue is dissolved, in hydrochloric acid; and the silex is separated, and estimated, as I have described [28]. The hydrochloric solution, from which the silex has been removed, is divided into three equal portions, which I shall call E, F, and H.

87. *Sulphuric acid.*—Part E is used, for determining the amount of *sulphuric acid*, in the same way as part B [81].

88. *Alkalies.*—Part F, to determine the alkalies, in the same way as one portion of D [85].

89. *Phosphoric acid, &c.*—Part H is mixed with ammonia, until a precipitate begins to appear; after which, acetic acid is added, and then acetate of soda. Phosphate of alumina, and phosphate of peroxide of iron, are thrown down; and the mixed precipitate will contain the whole of the phosphoric acid.—If there is no iron, in the liquor, it will be necessary to add perchloride of that metal, until a red colour is produced. The alumina, and oxide of iron, which—as well as the phosphates—would be thrown down, by the ammonia, are kept dissolved by the acetic acid. The mixture is boiled, for some time; and, while the solution is still hot, the phosphates are separated, by filtration. They are then placed in a porcelain dish, and dissolved in a little hydrochloric acid. Water—rendered alkaline, with ammonia—is next added to the solution; and, afterwards, hydrosulphuret of ammonia, in excess. The sulphuret of iron is filtered, washed with water containing hydrosulphuret of ammonia, and dissolved in hydrochloric acid; and, being boiled with nitric acid, its solution is added to the liquid, from which the phosphates of alumina and of iron were obtained—and which contain the lime, &c. The liquid from which the sulphuret of iron has been removed, is concentrated by evaporation; sulphate of magnesia is added, and it is carefully stirred:—the resulting crystalline basic phosphate is changed, by ignition, into pyrophosphate of magnesia—which contains 63·367 per cent. phosphoric acid. The iron, alumina, lime, magnesia, and manganese, are obtained in the way already described [29].

90. **CONSTITUENTS WHICH ARE INSOLUBLE IN WATER, AND**

DILUTE ACIDS.—The residue, after what is soluble in water, and in dilute acids has been removed [79 and 86], having been well dried, and finely pulverized, in an agate mortar, is transferred to a platinum crucible, along with about seven times its weight of concentrated sulphuric acid, and kept gently boiling, under a good chimney, until it is nearly dry. Hydrochloric acid is next added; then water; and, after being heated, the mixture is filtered. The clear liquor is divided into two parts; one is used to determine the alkalies [37], and the other to detect the phosphoric acid [24], alumina [31], lime [32], magnesia [33], and manganese [36].

91. CONSTITUENTS WHICH ARE INSOLUBLE IN WATER, AND ACIDS.—If the mass, which remained undissolved in concentrated sulphuric acid [90], dissolves entirely, in caustic potash, or carbonate of soda, it is pure silex, and may be estimated as before [28]. If not, being carefully dried, it is divided into two equal parts: and one of them is fused, with four times its weight of well-dried carbonate of potash [inorg. chem. 613]—a small piece of hydrate of potash being placed in a cavity, made in the middle of the mixture; the other, with rather more than the same quantity of carbonate of barytes. The mixture containing carbonate of potash or *white flux* is heated in a platinum crucible, until it fuses into a glass—which is tinted purple, if manganese, but red brown, if iron is present. While the crucible, and its contents, are still warm, they are placed, along with distilled water, in a porcelain capsule: and, hydrochloric [inorg. chem. 604], with a little nitric acid being added, the mixture is evaporated to dryness. The residue is heated, with dilute hydrochloric acid; and the silex being removed by filtration, is washed, dried, &c. [28.] The various substances, contained in the clear liquor, may be determined as before [86, &c.]

92. The part, which is fused with carbonate of barytes, will require an exceedingly high heat.—If fusion is produced, the most refractory minerals are then easily operated upon: if not, the process is imperfect. The platinum crucible, containing the barytic mixture is introduced into a fire-proof crucible, filled with magnesia, and is left in the furnace for a quarter of an hour. The result is treated in the same way as that, obtained by fusion with carbonate of potash [91].

When a mineral, &c., contains double or triple silicates of alumina, it is so refractory, that fusion with carbonate of potash, or barytes, is indispensable.

93. The phosphoric acid, obtained in the examination of a soil, though found in combination with alumina, and iron, may, in reality, have been united, at least in part, with lime, and magnesia.—The alumina and peroxide of iron being uncom-

bined, until hydrochloric set the phosphoric acid free, by decomposing the phosphates of lime, and magnesia.

94. *Manganese*.—This is generally found in soils, in such small quantities, that it is not necessary to separate it from the iron. It causes the latter, when exposed to the air, to assume a black colour.

95. *Fluorine*.—When, in an analysis, it is desirable, to ascertain the amount of fluorine, if the fluoride is soluble, it may be determined, by rendering the solution alkaline, with ammonia, and afterwards adding chloride of calcium. The resulting gelatinous fluoride of calcium must be washed on a filter, with hot water, and then with acetic acid—to remove any carbonate of lime, which may have been produced, during filtration. It contains 48·53 per cent. fluorine.

96. When the fluoride is insoluble, it is finely pulverized and intimately mixed with silex—unless it contains that substance; then placed in a small flask, and weighed: after which, sulphuric acid, that has been concentrated by boiling, is poured over it, and the flask is rapidly closed with a cork, in which has been inserted a tube that contains fused chloride of calcium in fragments, and has been drawn out to a fine point. The whole having been then weighed, the fluoride of silicon is driven off by heat, and the last portion is removed, by the exhausting syringe [55]. The weight lost is that of the fluoride of silicon—which contained 72·6 per cent. fluorine.

97. The analysis of the ashes of plants, is a very important subject; and will be greatly facilitated, by careful attention to what I have said regarding the analyses of soils, &c.

FRENCH MEASURES, &c.

Metre = 39·37079 inches.

Litre = 1·76076 pints.

Gramme = 15·433 grains.

These are subdivided, according to the decimal scale ; and the subdivisions are indicated by the Latin prefixes *deci*, *centi*, *milli*.—Thus, a decimetre is the tenth part of a metre : a centimetre, the hundredth part of a metre : and a millimetre, the thousandth part of a metre, &c. Tens, hundreds, thousands, millions of metres, &c., are indicated, respectively, by the Greek prefixes *deca*, *hecto*, *kilo*, and *myria*.—Thus, a decalitre, is ten litres : a myriagramme, a million of grammes, &c.

An *are*, the unit of superficial measure, is the square of a decametre : and a *stere*, the unit of solid measure, is the cube of a metre. A *litre* is the cube of a decimetre.

INDEX.

Aberration, 191.
 Absolute—motion, 11—sulphuric acid,
 442—alcohol, 605.
 Absorbent power of soils, 652.
 Absorption—of light, 167, 170—of heat,
 309, 310.
 Acaules, 555.
 Accelerated velocity, 11.
 Accessary integument, 561.
 Acetic—acid, 573—ether, 576.
 Acetone, 575.
 Acetous fermentation, 602.
 Acetyle, 576, 608.
 Acid—
 acetic, 573.
 aconitic, 581.
 adipic, 591.
 apocrenic, 621, 653.
 auric, 494.
 azoleic, 591.
 butyric, 592.
 capric, 592.
 caproic, 592.
 carbonic, 431.
 cetylic, 592.
 chloric, 455.
 chloroacetic, 575.
 chlorous, 455.
 citraconic, 581.
 citric, 579.
 crenic, 621, 653.
 cyanic, 568.
 elaidic, 590.
 ellagic, 585.
 formic, 576.
 fumaric, 582.
 gallic, 584.
 geic, 621.
 glucic, 601.
 humic, 621, 653.
 hydriodic, 459.
 hydrochloric, 455.
 hydrocyanic, 568.
 hydroferridecyanic, or ferridecyanide
 of hydrogen, 572.
 hydroferrocyanic, or ferrocyanide of
 hydrogen, 572.
 hydrofluoboric, 472.
 hydrofluoric, 462.
 hydrofluosilicic, 471.

Acid, *continued*—
 hydrosulphuric, 446.
 hypoacetous, 574.
 hypochlorous, 453.
 hyponitrous, 419.
 hyposulphurous, 441.
 itaconic, 581.
 lactic, 592.
 lipic, 591.
 maleic, 582.
 malic, 581.
 margaric, 589.
 melangallic, 585.
 melassic, 601.
 metapectic, 615.
 metaphosphoric, 449.
 mucic, 598, 601.
 muriatic, 456.
 nitric, 421.
 nitromuriatic, 458.
 nitrosonitric, 423.
 nitrous, 420.
 oleic, 590.
 oxalic, 566.
 oxypinic, 596.
 paratartaric, 579.
 parellagic, 585.
 pectic, 615.
 perchlorous, 455.
 phosphoric, 449.
 phosphorous, 449.
 pimelic, 591.
 pinic, 595.
 prussic, 568.
 pyrogallic, 585.
 pyroligneous, 574.
 pyroracemic, 579.
 pyrotartaric, 579.
 racemic, 579.
 saccharic, 600.
 saccharohumic, 600, 620.
 sacculmic, 599.
 sebacic, 590.
 silicic, 463.
 sorbic, 581.
 stearic, 588.
 suberic, 589.
 succinic, 589.
 sulphoglyceric, 587.
 sulphosaccharic, 600.

- Acid, *continued*—
 sulphovinic, 607.
 sulphuric, 442.
 sulphurous, 441.
 sylvic, 596.
 tannic, 582.
 tartaric, 578.
 tartralic, 579.
 tartrelic, 579.
 ulmic, 621.
 uric, 571.
 xanthoproteic, 613.
 Acids, 372.
 Acid salt, 375.
 Aconitic acid, 581.
 Acotyledenous plants, 553.
 Acromatic lens, 194.
 Acute harmonics, 155.
 Adipic acid, 591.
 Affinity, 391—changes the nature, form, and colour of substances, 392—is affected by nascent state, by quantity of matter, by temperature, 393, by partition of elements, by elasticity, 394, by light, 395—elective, 395—laws of, 397.
 Agamic plants, 553.
 Agate, 225.
 Air, 415—expansion of, 113, 321—properties of—its impenetrability—extension—inertia—elasticity, 138—its weight—pressure, 139, and constituents, 415—necessary for animals, and plants, 559—required for putrefaction, 619.
 Air gun, 140.
 Air pump, 142—experiments with, 144—of steam engine, 345.
 Air thermometer, 316.
 Air vessel—of fishes, 108—of hydraulic ram, 137—of forcing pump, 150.
 Albumen—vegetable, 612—animal, 613—soluble—coagulated, 613—detection of, 614—an antidote for corrosive sublimate, 512, 614.
 Albumum, 556.
 Alchemy, 366.
 Alcohol, 604—absolute, 605—effect of, on the system, 406—produced, during the manufacture of bread, 609—why it prevents putrefaction, 619.
 Alcoholic solution, 377.
 Aldehyd, 574.
 Algarotti, powder of, 477.
 Alkalies, 373, 426, 522, 530—vegetable, 616—detection of, 428, 525, 531, in water, 637—determination of, in water, 643, 644, in soils, 655.
 Alkaline salt, 375.
 Allotropic state, 399.
 Alloy, 494, 499.
 Alumina, 476—double and triple silicates of, 656—determination of, in water, 642, in soils, 655, 656.
 Aluminum, 475—compounds of—detection of, 476.
 Amalgam, 246—formed, by ammonia, 414.
 Amidogene, 428—compounds of, 608.
 Ammonia, 426—found in the atmosphere, 417—compounds of—carbonate of—nitrate of—sulphite of—sulphate of—oxalate of—hydrosulphuret of—427—detection of, 428, 637—determination of, in water, 644, in soils, 654—nature of, 428.
 Ammoniacal soap, 620.
 Ammonio-nitrate of silver, 529.
 Ammonio-sulphate of copper, 492.
 Ammonium, 428.
 Ammoniuret of silver, 529.
 Amorphous bodies, 382.
 Analysis, 376, 635—qualitative, 635, of water, 636, of organic substances, 646, of soils, 652—quantitative, 635, of water 637, of organic substances, 647, of soils, 653—arrangement of its results, 645.
 Analyzing mirror, 220.
 Anemometer, 165.
 Angle—of vision, how it affects the apparent size of objects, 176—of polarization, 169, 219.
 Angles of incidence, and reflection, 34, 169.
 Angular lever, 42, 80.
 Anhydrous substances, 376.
 Animal—force, 38—charcoal, 429, 430—albumen, 613—jelly, 616—matter, peculiar decomposition of, 620—manures, 628.
 Animals—a source of heat, 307—infusorial, 368—how they differ from plants, 552.
 Anions, 281.
 Annealing of glass, 468.
 Annular wheels, 56, 85.
 Anode, 281.
 Anther, 560.
 Anthracite, 619.
 Antidote, for—arsenic, 479—salts of copper, 491, 614—salts of lead, 504—corrosive sublimate, 512—oxalic acid, 567—prussic acid, 569—tartar emetic, 583.
 Antimony, 476—compounds of—detection of, 477.
 Appocrenic acid, 621, 653.
 Apparatus—chemical, 378, 379, 380, 383, 435, 438, 447, 582, 638, 646, 647, 648—for distillation, 389—Wolf's, 390—chloride of calcium, 649—potash, 649.
 Apparent level, 106.
 Aqua regia, 458.
 Aqueous—vapour, correction for, at different temperatures, 113—humour, 212—solution, 377, 381.
 Arabine, 598.

- Arched head, 332, 334.
 Archimedes—applies the doctrine of specific gravity, 111—screw of, 135, 136
 Arillus, 561.
 Arm, the human, 45.
 Aromatic vinegar, 575.
 Arsenic, 478—compounds of—detection of, 478—sometimes present in the human body—antidote for, 479.
 Arterial blood, 405.
 Ascent of bodies in fluids, 108.
 Asphyxia, caused by fermenting wine, 417.
 Astatic galvanometer, 295.
 Asthma, sometimes relieved by galvanism, 282.
 Astringent principle, 582.
 Astronomical telescope, 182.
 Atmosphere—of the planets, 368.—of the earth, constituents of, and substances found in, 415.
 Atmospheric electricity, 253.
 Atmospheric engine, 334.
 Atmospheric railway, 363.
 Atomic theory, 397.
 Atomic weight, 367.
 Attraction—chemical, 3, 391—of cohesion, 7—of gravitation, 13—capillary, 126—electrical, 230—magnetic, 287.
 Aurora borealis, 253.
 Axes of double refraction, 217.
 Axillæ, 556.
 Axis—real—resultant, 217—positive—negative, 218—neutral—depolarizing, 226.
 Axle—wheel and, 51—differential, 52.
 Azimuth compass, 291.
 Azoleic acid, 591.
 Azote, 413—terchloride of, 428.

 Backwater, of paddle wheels, 135.
 Balance—Roman—Danish—bent lever, 45—of a watch, 76—hydrostatic, 110.
 Balance wheel, 78.
 Ballistic pendulum, 20.
 Balloons, 108.
 Bands, 54, 87.
 Barium, 479—compounds of—chloride of—detection of, 480.
 Barker's mill, 133.
 Barley sugar, 599.
 Bar magnets, 288, 296.
 Barometer, 145—aneroid, 146—used to measure heights, and depths, 147.
 Barometer gauge, 143, 146—applied to condenser, 345.
 Bars, their rate of vibration, 161.
 Barytes, 480—nitrate of—chlorate of, 480—carbonate of, used in analysis, 656.
 Base, 373—saturating power of, 374.
 Bases of plants, variable in quality, but not in quantity, 559.
 Basic salt, 374.
 Basic water, 373.
 Baths, 328, 391.
 Battery—electric, 242—galvanic, 259—Cruikshank's—Wedgewood's—Wollaston's—Daniel's, 264—Grove's, 265—Smee's—Bunsen's—Callan's, 266—thermo-electric, 284.
 Battery connexions, 282, 301.
 Bell crank, 80.
 Bell metal, 491.
 Bellows—hydrostatic, 102—valve of, 340
 Bells, electrical, 234.
 Bent lever, 42.
 Bent lever balance, 45.
 Benzyle, 563.
 Berzelius's washing bottle, 379.
 Bevelled wheels, 56, 90.
 Bibasic acid, 374.
 Bichloride of platinum, 518.
 Binary compound, 372.
 Binding screws, 282.
 Bisalt, 374.
 Biscuit, 265, 465.
 Bismuth—compounds of—detection of, 481.
 Bisulphuret, 375.
 Bittern, 460.
 Black flux, 476.
 Black oxide of copper, 492, 647.
 Blast pipe, 335, 337.
 Bleaching, 451, 453—theory of, 451—by steam, 455.
 Bleaching salts, 453—will disinfect, and restore putrescent meat, 455.
 Bleeding, why useful, 406.
 Blistered steel, 499.
 Block tin, 534.
 Blood—globules of, 368—venous—arterial—contains phosphate of soda, oxide of iron, 405, and sulphocyanide of iron, 502.
 Blowing out, 341.
 Blow-pipe, 387—oxyhydrogen, 410.
 Boiler, 336—marine—locomotive, 336—for ordinary roads, 338—materials of, 341—explosion of, 324, 328, 329, 340.
 Boiling point, 328—affected by air in the fluid, 324, by pressure, but not that of the air, 328, and by the nature of the vessel, 329—enables us to determine heights, 329.
 Bones, 448—constituents of, 631, 632.
 Borda's turbine, 132.
 Boron, 471—compounds of, 472.
 Bottle glass, 468.
 Bramah's press, 102.
 Brass, 491.
 Bread, manufacture of, 609.
 Breast wheel, 129.
 Breezes, land, and sea, 165.
 Breguet's thermometer, 319.
 Brewing, 603.
 British gum, 597.
 Broad glass, 468.

- Bromine, 460—compounds of—detection of, 461, in water, 636—determination of, in water, 640, in organic substances, 651.
 Bronze, 491.
 Bronzing, by galvanism, 279.
 Bude burner, 403.
 Bude light, 403.
 Buds, 556.
 Buff, 197.
 Buildings—for public speaking, 163—protection of, from lightning, 254.
 Bulbs, 556.
 Bunsen's battery, 266.
 Burning glass, 175.
 Burning mirror, 186.
 Butter, 591—of antimony, 477.
 Butyral, 592.
 Butyric acid, 592.
 Butyrene, 592.

 Cadmium, 482—compounds of—detection of, 482.
 Caffeine, 617.
 Calamine, 541.
 Calcination, 474.
 Calcium, 482—compounds of, 482—chloride of, 484—detection of, 484.
 Callan's battery, 266.
 Calomel, 510.
 Caloric, 305.
 Calorimotor, 262.
 Calotype, 202.
 Calyx, 560.
 Cambium, 556.
 Camera lucida, 178.
 Camera obscura, 177, 196.
 Candle, 589—with hollow wick, 402—philosophical, 409.
 Cane sugar, 598.
 Caoutchouc, 596—tubes, and joints of, 386.
 Capacity—for electricity, 232, 243—for heat, 321.
 Capillary attraction, 126.
 Capric acid, 592.
 Caproic acid, 592.
 Capstan, 53, 57.
 Capstan bars, 53.
 Capsule, 384.
 Caramel, 599.
 Carat, 494.
 Carbon, 429—absorbs gases, 429—is anti-putrescent—decolourizes, 430—determination of, in organic substances, 650.
 Carbonate—of barytes, use of in analysis, 656—of copper, 491—of iron, 412, 498—of lead, 433, 504—of lime, 433, 483, as a manure, 634, detection of, in water, 637, in soils, 652, determination of, in water, 643—of magnesia, 507—of manganese, 508—of potash, 523, use of in analysis, 656—of soda, 530, 656.
 Carbonic acid, 431—produced, by respiration, 405—is present in the atmosphere, 417—is decomposed by plants, 433, 557—detection of, 433—determination of, 638, 654.
 Carbonic oxide, 430—produced in furnaces, 430—a compound radical, 567.
 Carburetted hydrogen, 434.
 Carnivorous animals, 324.
 Carrier wheel, 56.
 Carrigeen, 598.
 Case hardening, 500.
 Caseine, 614.
 Cassegranian telescope, 191.
 Cassius, purple of, 495, 536.
 Cast iron, 496—rendered malleable, 501.
 Cast steel, 499.
 Catalysis, 396, 565.
 Cataract, 215.
 Catoptrics, 183.
 Caulicle, 562.
 Caustic ammonia, 426—barytes, 480—lime, 483—potash, 522—soda, 530.
 Celestial observations, affected by refraction, 170.
 Cell—generating—decomposing, 275.
 Cellular substance, 556.
 Cementation, 383, 498.
 Centigrade thermometer, 318.
 Central forces, 26.
 Centre—of gravity, 23, 130—of suspension, 23, 43, 73—of gyration, 73—of oscillation, 73, 130—of percussion, 130.
 Centres, line of, 58.
 Centrifugal force, 26, 29, 32.
 Centrifugal pump, 151.
 Centripetal force, 26.
 Ceraine, 593.
 Cerine, 593.
 Cerium, 484—compounds of—detection of, 485.
 Cerosine, 593.
 Ceruse, 504.
 Cetine, 592.
 Cetyl, 593.
 Cetylic acid, 592.
 Chain pump, 131.
 Chain wheel, 131.
 Chairs, 360.
 Chalk, 483.
 Chalybeate springs, 412.
 Change of motion, 79.
 Charge—residual, 243—for galvanic battery, 263.
 Chemical action—of light, 195—the cause of galvanic effect, 257—a source of heat, 307, 375, 401.
 Chemical affinity, 391—exemplified, 392—affected by the nascent state, quantity of matter, heat, 393, partition of elements, elasticity, 394, light, and the presence of other bodies, 395.

- Chemical apparatus, 378, 379, 380, 383, 435, 438, 447, 582, 638, 646, 647, 648.
 Chemical attraction, 3, 391.
 Chemical changes, how represented, 376.
 Chemical effects—of electricity, 248—of galvanism, 269, 272.
 Chemical equivalents, 370.
 Chemical language, 372.
 Chemical processes, 376.
 Chemistry, 365—nature, history, and division of, 365—inorganic, 365—organic, 552.
 Chinese—have long used coal gas, 435—and liquid manure, 629, 630.
 Chladni, figures of, 161.
 Chlorate—of barytes, 480—of potash, 523, used in the manufacture of gunpowder, and lucifer matches, 524.
 Chloric acid, 455.
 Chloride—of barium, 480—of calcium, 485, used in analysis, 649—of potassium, 525—of silver, 453, 529—of zinc, 541.
 Chlorides, 375.
 Chlorimetry, 454.
 Chlorine, 450—it bleaches, and is a disinfectant, 451—it oxidizes powerfully, 452—action of, on organic substances, 564—compounds of, 452—detection of, 452, in water, 636, in organic substances, 647—determination of, in water, 640, in organic substances, 651, in soils, 654.
 Chloroacetic acid, 575.
 Chlorosulphurets, 375.
 Chlorous acid, 455.
 Choke damp, 432.
 Choroid coat, 212.
 Chromate of potash, 525.
 Chromatics, 192.
 Chromatype, 206.
 Chromium, 485—compounds of—detection of, 486.
 Cinnabar, 509—factitious, 510.
 Circles—pitch, 58—galvanic, 259.
 Circuit—electric, 242—galvanic, 260.
 Circular motion, 26.
 Circular polarization, 227—in fluids—obtained from rectilinear—changed into rectilinear, 228.
 Circumferentor, 291.
 Citraconic acid, 581.
 Citric acid, 579—detection of, 580.
 Claw hammer, 46.
 Clearance, 349.
 Cleavage, 382.
 Clocks—affected by sympathy, 158—electric, 298.
 Clouds, 235.
 Clutch, 89.
 Clypsydra, 71, 123.
 Coagulated albumen, 613.
 Coal, 429—formation of, 619, 620—composition of, 619.
 Coal gas, 434—manufacture of, 435.
 Cobalt, 487—compounds of—detection of, 488.
 Cock, 72, 337—gauge, 332, 339.
 Cohesion, attraction of, 7—table of, 8.
 Coke, manufacture of, 429, 436.
 Coke points, 268.
 Coking plate, 335.
 Cold—apparently reflected, 311—produced by evaporation, 324, 325, by liquefaction, 329—prevents putrefaction, 618.
 Collision of bodies, 19.
 Colophony, 595.
 Colour—affects electricity, 238—modified by heat, 305.
 Coloured rays, lengths, &c. of their respective waves, 210.
 Colours—of plates, and grooved surfaces, 210—complementary, 216.
 Columbium, 489—compounds of—detection of, 489.
 Column—of De Luc, 257, 264—of Volta, 263.
 Combination—of levers, 46—of pulleys, 48—of wheels and axles, 53—of inclined planes, 62, 65, 66.
 Combustion, 401—conditions of, 402—effected, under water, 393, 402—spontaneous, 403, 450, 451, 455, 484, 587.
 Comets, 219.
 Comparison of thermometers, 318.
 Compass—mariners', 290—azimuth, 291.
 Compensation balance, 77.
 Compensation pendulum, 75.
 Complementary colours, 216.
 Composition of forces, 24.
 Compound ethers, 608.
 Compound microscope, 180.
 Compression, a source of heat, 307.
 Concave mirrors—their foci of parallel convergent, 184, and divergent rays, 185.
 Concentration—of sound, 162—of light, 172, 184—of heat, 175, 186, 311.
 Condensed air fountain, 141, 144.
 Condenser, 139—of Volta, 232—of steam engine, 344—Hall's 345.
 Condensing engine, 333, 346.
 Conducting power, 235—modified by nature of the electricity, 237, and by heat, 305.
 Conduction—of sound, 152—of electricity, 235—of galvanism, 259—of heat, 307.
 Conductor—of electricity, 235—of galvanism, 259—of heat, 307—negative—prime or positive, 244—interrupted, 252, 254—action of, on magnet—is magnetic, 293—directive power of, 294.
 Confectioners' jelly, 616.
 Conical pendulum, 32.

- Conjugate foci, 173, 175, 184, 185.
 Connecting rod, 346—obliquity of, 82.
 Constituents—of the various kinds of glass, 468—of trees, shrubs, and herbs, 623, 626—organic, of the most common vegetable substances, 626, inorganic, 627—of urine, 628—of excrement, 629—of horse, and cow dung, 630—of guano, 631—of bones, 631, 632—of crust, and shell, 632—of peat, 633.
 Contact, communication of heat by, 309.
 Convergent rays, focus of, 173, 184, 187.
 Convex mirrors, their foci of parallel, convergent, and divergent rays, 187.
 Copper, 490—on ships' bottoms, how preserved, 262—deposition of, on daguerreotype plates, 280—sometimes causes danger with culinary vessels—compounds of, 491—black oxide of—sulphate of—ammonio-sulphate of—detection of, 492.
 Copper black, 491.
 Copper pyrites, 490.
 Cordage, rigidity of, 97.
 Cork, 556.
 Cornea, 212.
 Corolla, 560.
 Corrosive sublimate, 510—antidote for, 512.
 Cortical layers, 555.
 Cotyledons, 562.
 Couronne de tasses, 263.
 Crank, 82.
 Cream of lime, 437, 454.
 Crenic acid, 621, 653.
 Crown glass, 468.
 Crown wheel, 55—of a watch, 77.
 Crucibles, 384.
 Cruikshank's battery, 264.
 Crust, 448—constituents of, 632.
 Crutch, 72.
 Cryptogamic plants, 553.
 Crystal, 468—principal section of a, 217—unaxial, 226—left-handed—right-handed, 228.
 Crystalline forms, 381—secondary, 382.
 Crystalline humour, 212, 213.
 Crystallization, 381—caused by galvanism, 280—affected, by temperature, 306—injures the tenacity of iron, 381—systems of, 382—water of, 374, 376—facilitated by the presence of a solid body, 314.
 Crystals, 382.
 Currents, secondary, 300.
 Curves—descent down, 63—magnetic, 289—on railways, 362.
 Cushion, of steam, 356.
 Cutting of glass, 309, 391.
 Cyanide of potassium, 525.
 Cyanides, double, 568.
 Cyanogen, 567—compounds of, 568—detection of, 570.
 Cycloid, descent of bodies down, 65.
 Cylinder, 332, 342.
 Daguerreotype—process, 196—plates, produced by galvanism, 278, and etched, 279.
 Damascus steel, 499.
 Damper, 335.
 Daniel's battery, 264.
 Danish balance, 45.
 Davis's rotatory engine, 354.
 Davy's lamp, 409.
 Davy's laughing gas, 418.
 Davy's mode of preserving the copper on ships, 262.
 Decantation, 378.
 Decoction, 377.
 Decolourization, 430.
 Decomposing cell, 275.
 Decomposition, by galvanism—of water, 270—nature of, 281.
 Deflagration, 382.
 Deliquescence, 382.
 De Lisle's thermometer, 318.
 Deoxidizing flame, 387, 388.
 Descent of bodies, down planes and curves, 63.
 Destructive distillation, 381—of organic substances, 565.
 Deutoxide, 373.
 Dew, 326.
 Dew point, 325.
 Dextrine, 598.
 Diamond, 429—highly refractive, 170.
 Diamond lenses, 181.
 Diaphragm, 202.
 Diastase, 601.
 Didimium, 493.
 Differential axle, 52.
 Differential screw, 67.
 Digestion, 377—effected by galvanism, 283—of plants, 557.
 Dimorphism, 381.
 Diæcious flowers, 561.
 Dioptrics, 168.
 Dip, 289.
 Direct-action engine, 346.
 Direct percussion, 19.
 Direct shock, 254.
 Direction, line of, 23.
 Directive power, 287, 294.
 Disadvantages incident to machinery, 91.
 Disalt, 374.
 Discharge, 242.
 Discharger, universal, 250.
 Discharging rod, 246.
 Dished wheels, 61.
 Disinfectants, 423, 451, 455.
 Dispersive power, 194.
 Dissepiments, 561.
 Dissolving views, 179.

- Distance—mode of determining, 106, 183, 213—through which fluids will spout, 123—of lightning, 255.
- Distillation, 380, 604—destructive, 381—of organic substances, 565.
- Distilling apparatus, 389.
- Distribution of electricity, 243.
- Divergent rays, foci of, 174, 185, 187.
- Diving bell, 139.
- Divisibility of matter, 367.
- Dominant, 155.
- Double-acting engine, 334.
- Double cyanides, 568.
- Double decomposition, 394.
- Double filter, 378.
- Double salt, 376.
- Double refraction, 217—illustrated, 218.
- Doublet, 180.
- Doubly oblique prismatic system, 382.
- Draft, line of, 35, 93.
- Drill bow, 80.
- Driver wheel, 56.
- Dropping tube, 385.
- Drum, 87.
- Drummond's light, 410.
- Drying oils, 587—sometimes inflame spontaneously, 587.
- Dundonald's engine, 354.
- Duty of engines, 346.
- Dyeing, 396.
- Dynamical electricity, 258.
- Dynamical pressure, 93, 105.
- Dynamics, 1.
- Earth—revolution of, shown by pendulum, 76—a magnet, 289, 304—interior of, in a state of fusion, 306.
- Earthy soaps, 594.
- Ebullition, 323, 328.
- Eccentric, 85—fixed, 356.
- Eccentric pump, 150.
- Echo, 162.
- Eduction pipe, 332.
- Effective pressure, 333, 338, 339.
- Effects—of electricity, 247—of galvanism, 269—of heat, 305, 312.
- Effervescing drafts, 580.
- Efflorescence, 382.
- Elaïdic acid, 590.
- Elaïdine, 590.
- Elastic bodies, 19.
- Elastic fluids, 99.
- Elastic moulds, 275.
- Elastic tubes, how made, 386.
- Elasticity—of the air, 144—affects affinity, 394.
- Elective affinity, 395.
- Electrical—attraction, and repulsion, 230—dance—bells, 234—discharge circuit—shock, 242, 251—battery, 242—machine, 244—orrery, 248—pistol, 249—light, 252, 268—column, 257, 264—fishes, 286—clock—telegraph, 298—currents, 293, 300, 302.
- Electricity, 230—free, 230—sensible, 231—velocity of, 236—vitreous—resinous, 237—positive—negative, 238—nature of, affected by colour, temperature, 238, surface, and rubber, 239—nature of, how ascertained, 239—distribution of, 243—mechanical 247, 269, chemical, 248, 269, physiological, 251, 281, magnetic, 252, 293, optical, 252, 268, and atmospheric effects of, 253—statical, and dynamical, 258—produced by change of temperature, 283, by pressure, change of form, and evaporation, 285.
- Electrics, 235.
- Electrodes, 281.
- Electro lace, 278.
- Electrolyte, 281.
- Electro-magnet, 296.
- Electro-magnetic induction, 296.
- Electro-magnetism, 293—as a moving power, 297—identical with terrestrial magnetism, 303.
- Electrometer, 231—pith ball—gold leaf, 231—quadrant, 232—torsion, 233—self-discharging, or medical, 251.
- Electro-negative, and electro-positive bodies, 272, 369.
- Electrophorus, 246.
- Electroscope, 231.
- Electrotype moulds, 273.
- Electrotype process, 272—aided by electro-magnetism, 302.
- Elements, 369, 370—have a definite shape, 397—of organized substances, 553.
- Ellagic acid, 585.
- Elliptical—motion, 28—wheels, 88—polarization, 229.
- Embryo, 562.
- Emission of light, 167.
- Enamel, 465.
- Endless screw, 68.
- Endogenous plants, 555.
- Endosmose, 417.
- Endosperm, 562.
- Engine—water pressure, 134, 363—Hero's, 331—Newcomen's, 332—atmospheric, 332, 334—high pressure—low pressure—condensing—non-condensing, 333—single, and double acting, 334—direct action, 346—Hornblower's—oscillating, 352—rotary, 353—Dundonald's—Davis's, 354—gravitation, 355—marine, 358—locomotive, 359.
- Engines, power, and duty of, 346.
- Epicycloidal teeth, 58.
- Epidermis, 556.
- Episperm, 562.
- Epsom salts, 579.
- Equilibrium, stable, and unstable, 23.

- Equivalents — chemical, 367, 369 —
 table of, 370.
 Erbium, 493.
 Escapement, 72.
 Escapement wheel, 72.
 Essential oils, distillation of, 324.
 Etching of daguerreotype plates, 279.
 Ethal, 592, 593.
 Ether, 607—acetic, 576.
 Ethereal solution, 377.
 Etherine, 605.
 Ethers, compound, 608.
 Ethyle, 608—oxide of, 606.
 Eudiometer, 416.
 Evaporation, 323—capability of, com-
 municated to solids, 324—produces
 cold, 324, 325—retarded by the air,
 325—affected by pressure, but not
 that of the air, 328.
 Excrement, constituents of, 629.
 Excretions of plants, 554.
 Exercise, effect of, 407.
 Exogenous plants, 555, 559.
 Exosmose, 417.
 Expansion—caused by heat, 113, 317
 —applied, 312—counteracted, 75,
 77, 313—of certain bodies, 314—
 connected with fusibility, 314.
 Expansion joints, 313.
 Expansive action of steam, 351, 358.
 Expiration, 405—of leaves, 557.
 Explosion, 403—of mixed gases, how
 prevented, 271, 411, 449—of steam
 boilers, 324, 328, 329, 340, 341—of
 mines, how prevented, 409—why
 destructive to life, 410.
 Extension, 2.
 Extractive matter, 612.
 Extraordinary ray, 217.
 Eye, 211—orbit of—description of, 212
 —not affected by spherical aberration,
 214—sometimes insensible to
 colour, 215.
 Eye glass, 180, 182.
 Eyes—of fishes—of insects, 214.
 Face, of tooth, 58.
 Fahrenheit's thermometer, 318.
 Fairy rings, 555.
 Falling stars, 253.
 Fallowing, use of, 555, 559.
 Fan, 78.
 Fast pulley, 89.
 Fat—use of, 407—formation of, 592.
 Fat lute, 390.
 Fats, 586.
 Feathering, of paddle wheels, 135.
 Ferment, 602.
 Fermentation — saccharine — vinous —
 acetous — viscous — mucilaginous,
 602—putrefactive, 602, 617—lactic,
 602—panary, 602, 609.
 Ferridcyanide—of hydrogen, 572—of
 potassium, 573.
 Ferridcyanogen, 572.
 Ferrocyanide—of hydrogen, 572—of
 potassium, 573.
 Ferrocyanogen, 572.
 Ferrottype, 205.
 Fibrine, 612.
 Field glass, 180.
 Field of view, 180.
 Figures, of Chladni, 161.
 Filament, 560.
 Filters—single—double, 378.
 Filtration, 378—with pounded glass,
 380—without communication with
 the atmosphere, 380.
 Fining of liquors, 604.
 Fire box, 337.
 Fire damp, 434.
 Fire engine, 150.
 First shot, 605.
 Fishes—air vessels of, 108—eyes of, 214
 —electrical, 286—respiration of, 407
 —cannot live in mountain lakes, 413.
 Fixation of daguerreotype picture,
 196, 200, 203.
 Fixed air, 431.
 Fixed eccentric, 356.
 Fixed oils, 586.
 Fixed pulley, 47.
 Flame—deoxidizing or reducing—oxi-
 dizing, 387, 388—at the mouth of a
 gun, 425.
 Flank of tooth, 58.
 Flats, 155, 156.
 Flint glass, 467.
 Floral integument, 560.
 Floral leaves, 560, 561.
 Flower—monopetalous, &c.—monose-
 palous, &c., 560—monæcious, &c.—
 sessile, &c.—hermaphrodite, 561.
 Flowers—coating of, by electrotype,
 274—of sulphur, 440—of zinc, 541.
 Fluids—affected by cohesion, 7—
 nature of—perfect—imperfect—
 elastic, 98—non-elastic, 99—pres-
 sure of, 99, 105—surfaces of, 105—
 ascent of bodies in, 108—specific
 gravity of, 111, 112, 117—resistance
 of, 119—spouting, 121—motion of, in
 pipes, 124—mutual repulsion of, 127
 —how heated, 308—why some cool
 very slowly, 309.
 Fluoride—of calcium, 462—of silicon,
 471—of boron, 472.
 Fluorine, 461—compounds of, 462—
 detection of, in water, 636—deter-
 mination of, 657.
 Fluorotype, 205.
 Fluosilicates, 463.
 Flux—black, 476—white, 656.
 Fly, 70.
 Fly wheel, 69.
 Flying bridges, 36.
 Foci—of lenses, 172—conjugate, 175,
 176, 184, 185, 186—of mirrors, 184.

- Focus, 170, 184—real, 170—imaginary or virtual, 170, 185, 187—principal—geometrical, 171—of convergent rays, 173, 174, 184, 187—of divergent, 174, 185, 187.
- Follower, 56.
- Force, 11—accelerating—retarding—of gravity, 13, measured by the pendulum, 75—centrifugal—centripetal—tangential, 26—sources of, 36—of the wind, 36, 165—of animals, 38—of vapour, 323.
- Forces—composition of, 24—resolution of, 24, 34—resultant of, 25, 34.
- Forcing pump, 149.
- Form, change of, produces electricity, 285.
- Formic acid, 576—detection of, 577.
- Formyle—compounds of, 577.
- Fountain—condensed air, 141, 144—Hero's, 141—rarified air, 144—syphon, 152.
- Free electricity, 230.
- Freezing mixtures, 329.
- French weights, &c., 658.
- Friction, 91—on planes, 92—laws of, 95—generates heat, 307.
- Friction—wheels, and rollers, 96—brake, 350.
- Frost, effects of, 315.
- Fruit—its action on the air—ripening of, 562.
- Fuel—consumption of, in engines, 350—for locomotives, &c., 360—how injured by damp, 404.
- Fulcrum, 41—of a balance, 44.
- Fulminating gold, 495.
- Fumaric acid, 582.
- Fusible metal, 114, 273.
- Fusible metal moulds, 273.
- Fusion—aqueous, 381.
- Galena, 502.
- Galic acid, 584—detection of, 585.
- Galls, 582—infusion, and tincture of, 583.
- Galvanic battery, 259—Volta's, 263—Cruikshank's—Wedgewood's—Wollaston's—Daniel's, 264—Grove's, 265—Smee's—Bunsen's—Callan's, 266—decomposes water, 270—connections, 267, 282, 301—positive, and negative poles of, 258, 262, 263, 272—positive, and negative elements of, 260, 262—charges for, 263.
- Galvanic circles, 259—how they produce an effect—how they are combined, 260—their electrical states, 261.
- Galvanic current, 260—magnetic effect of, 293.
- Galvanism, 256—due to chemical action, 257—nature of—how connected with electricity, 258—remarkable for quantity, 269—chemical, 269, physiological, 281, and magnetic effects of, 293—how it decomposes water, 282—sometimes useful in medicine, 280.
- Galvanometer, 295—astatic, 295—torsion, 296.
- Gamut, 155.
- Gas—naphthalized—portable, 439.
- Gas engine, 364.
- Gas holder, 388, 437.
- Gas metre, 438.
- Gases—specific gravity of, 112—their volume affected by pressure, 148, by temperature, 321, and by their hygrometric state, 327—combine in volumes, 398—absorbed by water, 413, by charcoal, 429—narcotic, irritant, neutral, 414—mix, though of different densities—afford a vacuum to each other—pass through membranes, and tissues, 417—for illumination, 434.
- Gastric juice, 458.
- Gauge—barometer, 143, 146—syphon, 143.
- Gauge cocks, 332, 339.
- Gearing, 88.
- Geic acid, 621.
- Gelatine, 615.
- Gemmule, 562.
- Generating circle, 58.
- Generating cell, 275.
- Geometrical focus, 171.
- German oil of vitriol, 442.
- German silver, 515.
- Gland, 313, 344.
- Glass—method of cutting, 309, 391—engraving of, by hydrofluoric acid, 462—manufacture of—malleable, 466—different kinds of, 466, 468—annealing of, 468—staining of, 469—gilding of—soluble, 470.
- Glassmakers' soap, 508.
- Glazing of porcelain, 465.
- Glucic acid, 601.
- Glucina, 493.
- Glucinum—detection of, 493.
- Glucose, 600.
- Glue, 616.
- Gluten, 612.
- Glycerine, 586, 587.
- Glyceryle, 586.
- Gold, 493—compounds of—peroxide of, 494—perchloride of—detection of, 495.
- Governor, 78, 342, 357.
- Grain soap, 595.
- Grain tin, 534.
- Grape sugar, 600.
- Graphite, 429.
- Grave harmonics, 157.
- Gravitation, 3—laws of, 13.
- Gravitation engine, 355.
- Gravity, 13—centre of, 23—force of, how ascertained, 75.
- Green crops, why beneficial, 555, 557, 563.
- Gregorian telescope, 190.
- Gridiron pendulum, 75.

- Grotto del cane, 432.
 Grove's battery, 265.
 Guano, 631—constituents of, 631.
 Guiding wires, 274.
 Gum, 598—British, 597—Arabic—
 Senegal, 598.
 Gum resin, 596.
 Gun—bursting of, 2—recoil of, 9—
 flame, at mouth of, 425.
 Gun cotton, 611.
 Gun metal, 491.
 Gunpowder, 424—products of its igni-
 tion, 424.
 Gutta percha, 597—moulds, 275.
 Gypsum, 483, 634.
 Gyration, centre of, 73.

 Hair, forms a soap, 595.
 Hair spring, 77.
 Hall's condenser, 345.
 Haloid salts, 373.
 Halos, 210.
 Hammer, 18, 46.
 Hard solder, 491.
 Hard water, 594.
 Harmonics — acute, 155 — grave,
 157.
 Harmony, 157.
 Head of water, 129.
 Hearing trumpet, 162.
 Heart wood, 556.
 Heat, 305—causes repulsion, 8—impor-
 tance of—affects conducting power,
 magnetism, malleability, colour, 305,
 and crystallization, 306—nature, and
 sources of, 306—conductors of, 307—
 radiation of, 309—absorption of—
 transmission of, 310—reflection of,
 311—how it differs from light, 311—
 expansion caused by, 312—specific,
 321—sensible, 315, 322—latent, 322
 —modifies affinity, 393—how pro-
 duced in the animal body, 405—
 necessary for, and secured to plants,
 560—causes putrefaction, 618, pre-
 vents it, 619.
 Heating surface, 335.
 Height of mountains—measured by
 pendulum, 75, and by the boiling
 point of water, 329.
 Helix, 296—insulation of, 297—inten-
 sity, from—quantity, from, 300—pri-
 mary—secondary, 302.
 Hematite, red, 498.
 Hepatic respiration, 407.
 Herbaceous integument, 555.
 Herbs, ashes of, 623.
 Hermaphrodite flowers, 561.
 Hero's engine, 331.
 Hero's fountain, 141.
 Hessian crucible, 384.
 High pressure engine, 333.
 High pressure steam, 333—used for
 bleaching, 455.
 Hilum, 562.

 Hollow screw, 67.
 Hook's universal joint, 84.
 Hops, 603.
 Horizon, visible, 106.
 Horizontal—movement, 78 — water
 wheel, 132.
 Hornblower's engine, 352.
 Horse power, 346, 350.
 Horse-shoe magnet, 288, 296.
 Hour glass, 100.
 House pump, 148.
 Human arm, 45.
 Humic acid, 621—determination of, in
 soils, 653.
 Humine, 621—determination of, in
 soils, 653.
 Humour—crystalline, 212, 213, 214,
 215—aqueous—vitreous, 212.
 Humous acid, 621—determination of,
 in soils, 653.
 Hungarian machine, 142.
 Hunting cog, 59.
 Hydraulic press, 102.
 Hydraulic pressure, 105.
 Hydraulics, 98, 128.
 Hibernating animals, 407.
 Hydracids, 373—really salts, 408.
 Hydrate, 375—of lime, 375, 483—of
 potash, 523—of soda, 530.
 Hydriodic acid, 459.
 Hydrochloric acid, 455—employed in
 making bread, 609.
 Hydrocyanic acid, 568.
 Hydrodynamic pressure, 105.
 Hydrodynamics, 98.
 Hydro-electricity, 285.
 Hydrostatic bellows, 102.
 Hydrostatic paradox, 101.
 Hydrostatic press, 102.
 Hydrostatic pressure, 99.
 Hydroferridcyanic acid, 572.
 Hydroferrocyanic acid, 572.
 Hydrofluoric acid, 462—used to engrave
 glass, 462.
 Hydrofluosilicic acid, 463.
 Hydrogen, 407—oxide of, 409—per-
 oxide of, 412—sulphuretted, 446—
 ferrocyanide of, 572—ferridcyanide
 of, 572—determination of, in organic
 substances, 650.
 Hydrosulphuret of ammonia, 427.
 Hydrosulphuric acid, 446.
 Hygrometer, 325—wet bulb, 326.
 Hypoacetic acid, 574.
 Hypochlorous acid, 453.
 Hyposulphite of soda, 531.
 Hyposulphurous acid, 441.

 Ice—produced in a vessel intensely hot,
 10—advantage of its being lighter
 than water, 314.
 Iceland moss, 598.
 Iceland spar, 217, 226.
 Ignition of a precipitate, 380.
 Ilimenium, 495.

- Images—formed by lenses, 175—by mirrors, 187—may be considered as new objects, 176.
 Imaginary focus, 170, 187.
 Impact, 19—wheels, 132.
 Impact and reaction wheels, 132.
 Impenetrability, 1—of the air, 138.
 Incidence, angle of, 34, 169—when equal to that of reflection, 34.
 Incineration, 382.
 Inclined plane, 61.
 Inclined planes—descent of bodies down, 63—on railways, 361.
 Index of refraction, 169—affected by obliquity of incidence, 170.
 Indices of refraction—for various substances, 169—for coloured rays, 193.
 Indigo, 397.
 Induction—electrical, 239—magnetic, 289, 291—electro-magnetic, 296.
 Inertia, 2—the cause of centrifugal force, 26—of the air, 138.
 Inflammability, connected with refractive power, 170.
 Infusion, 377—of galls, 583.
 Infusional animals, 368.
 Injection pipe, 332.
 Injection cistern, 332.
 Ink, 583.
 Inorganic chemistry, 365.
 Inorganic matter, 552.
 Innervation, 552.
 Insects—eyes of, 214—coated with metals, 274.
 Insulating stool, 236.
 Insulation, 236.
 Integument—herbaceous, 555—floral, 560—accessary, 561.
 Intensity—of sound, 153—of light, 167, 411—of electricity, 231, 250, 269—obtained with galvanic battery, 260, and with electro-magnetic helix, 302.
 Interference—of sound, 163—of ordinary light, 208—of polarized light, 225.
 Interrupted conductors, 252, 254.
 Ions, 281.
 Involucellum, 561.
 Involucre, 561.
 Iodide of potassium, 525.
 Iodides, 375.
 Iodine, 459—compounds of—detection of, 460, in water, 636, in organic substances, 647—determination of, in water, 640, in organic substances, 651, in a soil, 654, 656.
 Iridium, 495—compounds of—detection of, 496.
 Iris, 212.
 Iron, 496—tenacity of, injured by crystallization, 381—tinned by galvanism 279—found in the blood, 405—it welds—is rendered passive—rust of—compounds of, 497—oxides of, 498—protoxide of, injurious to soils, 633—protosulphate of—sulphuret of—steel, 498—detection of, 501, in water, 637, in soils, 652—determination of, in water, 641, 643, in soils, 655.
 Iron moulds, 580.
 Irrationality of the spectrum, 194.
 Irrespirable gases, 414.
 Irritant gases, 414.
 Isinglass, 616.
 Isomerism, 398.
 Isomorphism, 399.
 Itaconic acid, 581.
 Ivory black, 429.
 Jelly—vegetable, 615—confectioners', 616.
 Joints—expansion, 313—of caoutchouc, 390.
 Kaleidoscope, 188.
 Kathode, 281.
 Kation, 281.
 Keeper, 288, 296.
 Kelp, 459.
 Key note, 155.
 Keys, 56.
 Kreosote, 574, 618.
 Lactic acid, 592.
 Lactic fermentation, 602.
 Lactine, 601.
 Lagaroust, lever of, 84.
 Lamp—flame of, 387—Davy's, 409.
 Lampblack, 429.
 Land breezes, 165.
 Language, chemical, 372.
 Lantern—or trundle, 57—magic, 178.
 Lanthanum, 502—detection of, 502.
 Latent heat, 322.
 Lateral—draft of streams, 125, 131—aberration, 192.
 Laughing gas, 418.
 Law of Mariotte, 140.
 Laws of affinity, 397.
 Lead, 502—deposited by galvanism, 279—compounds of, 503—oxides of, 503—carbonates of—neutral acetate of, 504—detection of, 505—poisonous effects of, 504—antidote for, 504.
 Leather, 583, 616—manufacture of, 583.
 Leaven, 609.
 Leaves, 556—of pinions, 53—sessile, &c.—nerves of—exhale moisture, and absorb nutriment—fall of, 557.
 Left-handed crystal, 228.
 Legumine, 612.
 Length of pendulum, 73.
 Lens, 171—magnifying power of—increases the brightness of objects, 177—diamond, 181—acromatic, 194.
 Lenses—foci of, 172—images formed by, 175.

- Leucine, 614.
 Level—real—apparent, 106.
 Levels, 107.
 Lever, 41, 46—angular, 42—applied to measure weight, 43—of Lagaroust, 84.
 Levers—combinations of, 46.
 Ley, 594.
 Leyden jar, 241.
 Liber, 556.
 Lichenine, 598.
 Life, seemingly restored by galvanism, 283.
 Lifting pump, 149.
 Light—sources of—nature of, 166—emission of—intensity of—velocity of, 167—of self-luminous bodies—refraction of, 168—reflection of, 183—decomposition of, 192, 217—chemical action of, 195—interference of, 208, 225—double refraction of, 217—electric, 252, 268—it affects the needle, 290—is affected by an electric current, 302—how it differs from heat, 311—modifies affinity, 395—required by plants, 558—injurious to seeds, 563.
 Light carburetted hydrogen, 434.
 Lightning—identical with electricity, 253—protection from, 254—distance of, 255.
 Lignine, 610.
 Lime, 483—hydrate of, sometimes causes ships to be burned, 375—bleaching salts of, 454—carbonate of—sulphate of, 483—phosphate of, 484—detection of, in water, 637—determination of, in water, 642, 643, in soils, 655, 656.
 Lime light, 410.
 Limestone, 483—detection of, in soils, 652.
 Limiting angle of resistance, 94.
 Line—of direction, 23—of centres, 58—of draft, 35, 60, 93.
 Lines—of double refraction, 217—of no polarization, 227.
 Lipic acid, 591.
 Lipyle, 588.
 Liqutation, 534.
 Litharge, 503, 528.
 Lithia, 506—determination of, in water, 644.
 Lithium, 505—compounds of—detection of, 506.
 Lithographic printing, 10.
 Liver—why affected, in hot climates, 416.
 Lixiviation, 377.
 Loadstone, 287, 288.
 Loaf sugar, 599.
 Locomotive boiler, 336.
 Locomotive engine, 359, 362.
 Locomotives—speed of, 361—on ordinary roads, 362.
 Longitudinal aberration, 191.
 Low-pressure engines, 333.
 Lubrication, 97.
 Lucifer matches, 524.
 Lunar caustic, 529.
 Lungs, affected by the hygrometric state of the air, 326.
 Luting, 390.
 Maceration, 377.
 Machine—electrical, 244, 303—for giving shocks, 301, its principle applied to the electrotype, 302.
 Machinery—regulation of, 69—disadvantages incident to, 91.
 Magic lantern, 178.
 Magnesia, 507—detection of, in water, 637—determination of, in water, 641, in soils, 656.
 Magnesium, 506—compounds of—detection of, 507.
 Magnet—different kinds of, 288, 292, 296—action of, on iron, and steel, 291.
 Magnetic—induction, 289, 296—attraction, 289, laws of, 289—rotations, 294.
 Magnetic effects—of electricity, 252—of galvanism, 293.
 Magnetism, 287—nature of, 288—produced by electricity, 252, 293, by rotation, 302—affected by temperature, 305.
 Magnetization, 291.
 Magnifying power—of a lens, 177—of microscopes, 180, 181—of telescopes, 182, 191.
 Maleic acid, 582.
 Malic acid, 581—detection of, 581.
 Malleable cast iron, 501.
 Malleable glass, 466.
 Malleability, affected by temperature, 305.
 Manganese, 507—compounds of—detection of, 508, 657, as peroxide, in soils, 652—determination of, in water, 643—in soils, 655, 656.
 Mannheim gold, 491.
 Mannite, 601.
 Manometer, 148.
 Manoscope, 148.
 Manufacture—of shot, 126—of sal-ammoniac, 427—of coal gas, 434—of oil gas, 439—of sulphuric acid, 443—of porcelain, 464—of glass, 466—of carbonate of soda, 530—of vinegar, 574—of leather, 583—of soap, 593—of beer, &c., 603—of ardent spirits, &c., 605—of bread, 609.
 Manures, 628—animal, 628—vegetable—mineral, 633.
 Marble, 483—fusion of, 483.
 Margarinic acid, 588, 589.
 Margarine, 586, 589.

- Margarone, 588, 589.
 Margaryle, 590.
 Marine boiler, 336.
 Marine engine, 358.
 Mariotte, law of, 140.
 Marquess of Worcester's mode of raising water, 331.
 Marsh gas, 434.
 Mashing, 603.
 Massicott, 503.
 Mattress, 383.
 Matter, 1 — properties of, 1 — divisibility of, 367—organized—inorganic, 552—extractive, 612.
 Mean refraction of a prism, 194.
 Meat, when putrescent, restored by chlorine, 455.
 Mechanical—powers, 40—effects of electricity, 247, of galvanism, 269.
 Medical electricity, 251—from galvanism, 282—from electro-magnetism, 301.
 Medium—of sound, 152—of light, 167.
 Medullary rays, 555.
 Melangallic acid, 585.
 Melassic acid, 601.
 Melody, 157.
 Memory, connected with vision, 215.
 Mercurial—pendulum, 75—apparatus, 200—gauge, 340.
 Mercury, 509 — compounds of — peroxide of—protonitrate of—perchloride of, 510—detection of, 511.
 Metacetone, 600.
 Metallic packing, 344.
 Metallic soaps, 594.
 Metals—general properties of, 473—classification of, 474—ancient symbols for, 505—comportment of, with re-agents, 542.
 Metapeptic acid, 615.
 Metaphosphoric acid, 449.
 Meteoric stones, 16, 323.
 Metronome, 74.
 Miasmata, 415.
 Mica, 226, 311.
 Microcosmic salt, 531.
 Micrometer screw, 68.
 Microscope, 179—refracting—single or simple, 179—compound, 180—oxy-hydrogen, 181—reflecting, 190—magnifying power of, 180, 181.
 Midrib, 557.
 Mill stones, mode of forming, 325.
 Mineral manures, 633.
 Mineral waters, 412—analysis of, 636.
 Mirror, 183—plane, 183, 187—concave, 183, 184, 188—convex, 183, 186, 189—burning, 186—images formed by, 187—polarizing—analyzing, 220.
 Mirrors, silvering of, 511.
 Mixed gases—united by platinum, by putrescent substances, 412, by light, 195, 456.
 Mock suns, 208.
 Modulation, 156.
 Molasses, 599.
 Molybdenum, 513—compounds of—detection of, 513.
 Momentum, 17.
 Monobasic acids, 374.
 Moon, causes tides, 5.
 Mordants, 393.
 Mortars, 386.
 Motion, 10—absolute—relative, 11—circular, 26—elliptical, 28—of projectiles, 35—perpetual, 40—change of, 79—reversion of, 90—of bodies in fluids, 120—of fluids in pipes, 121.
 Mottled soap, 594.
 Moulds, 273—of fusible metal, 273—of wax—of plaster, 274—elastic—of gutta percha, 275.
 Movable pulley, 47, 48.
 Mucic acid, 598, 601.
 Mucilage, 598.
 Mucin, 612.
 Mucous fermentation, 601.
 Mucus, vegetable, 598.
 Muffed glass, 172.
 Multiplier, thermo-electric, of Nobili, 284.
 Multiplying glass, 172.
 Muriatic acid, 456.
 Muscovado, 599.
 Musical sounds, 155—produced by burning hydrogen, 409.
 Musket ball, range of, 35.
 Myracine, 593.
 Naphthaline, 436.
 Naphthalized gas, 439.
 Narcotic gases, 414.
 Nascent state, 393.
 Nature—of light, 166—of electricity, 237—of galvanism, 257, 260—of magnetism, 303.
 Neap tides, 6.
 Needle, 288—affected by light, 290, by the iron in ships, 292, by electricity, 293.
 Negative—picture, 196—axis, 218—electricity, 237, 238—conductor, 244—element, 262, 281—pole, 262, 281—or neutral gases, 414.
 Nerves—of digestion, 283—of leaves, 557.
 Nervous fluid, 283.
 Neutral—axis, 226—salt, 375—or negative gases, 414.
 Newcomen's engine, 332.
 Newtonian telescope, 191.
 Nickel, 514—compounds of, 514—detection of, 515.
 Niobium, 515—detection of, 515.
 Nitrate—of soda, 422, 424—of potash, 424—of ammonia, 427—of barytes, 480—of mercury, 510—of silver, 529.

- Porcelain, 464—manufacture of, 464—
 Reaumur's, 467.
 Porous ware, 265.
 Portable gas, 439.
 Positive—picture, 196—axis, 218—elec-
 tricity, 238—conductor, 244—ele-
 ment, 260, 281—pole, 281.
 Potash, 522—caustic, 552, its action on
 organic substances, 565—bleaching
 salt of, 454—carbonate of, 523, used
 in analysis, 656—sulphate of—chlo-
 rate of, 523—antimoniate of, 524—
 chromate of, 525—detection of, in
 water, 637—determination of, in
 water, 643, in soils, 654, 655.
 Potash apparatus, 649.
 Potassa, 522.
 Potassium, 521—compounds of, 522—
 chloride of—iodide of—sulphuret of,
 525—cyanide of, 525—ferrocyanide of
 —ferridcyanide of—sulphocyanide of,
 573—detection of, 525.
 Potato—shoots of, sometimes poisonous,
 558—frozen, 597—how preserved,
 598.
 Power, 40—of water wheels, 131—of
 steam engines, 346, 361.
 Powers, mechanical, 40.
 Precipitate, 377—washing of—weighing
 of, 379—ignition of, 380.
 Precipitation, 377.
 Press—Bramah's hydraulic, 102—for
 electrical experiments, 250.
 Pressure—of bodies in motion, 93—of
 fluids, at rest, 99—of fluids, in mo-
 tion, 105—of the air, 139, 144, 147—
 produces electricity, 285—affects
 boiling point, 328, 329.
 Pressure wheels, 133.
 Primary—bow, 206—helix, 302—com-
 pounds, 372.
 Prime mover, 40.
 Prime conductor, 244.
 Priming, 337.
 Principal—focus, 171—section a crystal,
 218.
 Printing, lithographic, 10.
 Prism, 192—mean refraction of, 194—
 of rock salt, 310.
 Prismatic system, 382.
 Processes, chemical, 376.
 Projectiles, path of, 35.
 Properties—of matter, 1—of the air,
 138—of the spectrum, 195.
 Protection from lightning, 254.
 Protein, 614.
 Protochloride of tin, 535.
 Protonitrate of mercury, 510.
 Protosalt, 374.
 Protosulphate of iron, 498—a test for
 nitric acid, 426.
 Protoxide, 373.
 Prussian blue, 502, 570—basic, 569.
 Prussiate of potash—yellow—red, 573.
 Prussic acid, 568—antidotes for, 569—
 strength of, how determined—detection
 of, 570.
 Public speaking, buildings for, 163.
 Pudling, 496.
 Pulley, 47—fixed—movable, 47—
 White's, 49—fast, and loose, 89.
 Pulleys, combinations of, 48.
 Pumps, 131, 148, 338, 345, 346, 359.
 Pupil, 212.
 Purple of Cassius, 495, 536.
 Pyramid, 351.
 Pyrites—copper, 490—iron, 498.
 Pyrogallic acid, 585.
 Pyroligneous acid, 574.
 Pyrometer, 320.
 Pyrophosphate—of soda, 374—of mag-
 nesia, 655.
 Pyrophosphoric acid, 449.
 Pyrroacemic acid, 579.
 Pyrotartaric acid, 579.
 Pyroxyle, 611.
 Pyroxyline, 611.
 Putrefaction—how prevented, 618.
 Putrefactive fermentation, 602, 617.
 Putrescent meat, restored by chlorine,
 455.
 Quadrant electrometer, 232.
 Qualitative analysis, 635—of water,
 636—of organic substances, 646—of
 soils, 652.
 Quality of sound, 155.
 Quantitative analysis, 635—of water,
 637—of organic substances, 647—of
 soils, 653.
 Quantity—of electricity, 231, arrange-
 ment for, 258, 260, 300—of matter,
 modifies affinity, 393.
 Quartation, 423.
 Quaternary compound, 372.
 Racemic acid, 579.
 Rack, 59, 79.
 Radiant point, 173.
 Radiation—of light, 167—of heat, 309,
 from certain substances, 309.
 Radical, 372, 563—compound, 445, 563.
 Radicle, 562.
 Rain, cause of, 326.
 Rainbow, 206—primary, 206—second-
 ary, 207.
 Ram, hydraulic, 136.
 Range—of a projectile, 35—of hearing,
 155.
 Ratchet, 57.
 Ratchet wheel, 57.
 Rate of vibration—not alterable, 159—
 of strings, &c., 160.
 Ratio of the sines, 169.
 Ray, 167—coloured, 193—calorific—
 chemical, 195—ordinary—extraordi-
 nary, 217.
 Reaction, 18—of a plane, 18.

- Reaction wheels, 133.
 Re-agents, 378—comportment of the metals with, 542.
 Real—level, 106—focus, 170.
 Realgar, 478.
 Reaumur's—thermometer, 318—porcelain, 467.
 Receiver, 143.
 Receivers, chemical, 384.
 Recoil of a gun, 9.
 Rectification, 605.
 Red lead, 503.
 Red precipitate, 510.
 Reducing flame, 387.
 Reduction—of oxides—of sulphurets, 473.
 Reflecting—microscope—telescope, 190.
 Reflection—angle of, 34, 169—of sound, 162—plane of, 183—of heat—apparent, of cold, 311.
 Refracting — microscope, 179 — telescope, 182.
 Refraction—of light, 168—of heat, 310—angle of, 169—index of, 169—affects celestial observations, 170—through a plane glass—through a prism, 171—through a lens, 172—double, 217.
 Regular structure, 382.
 Regulation—of machinery, 69—of a watch, 70, 76—of a clock, 71.
 Relative—motion, 11—velocity, 40.
 Reptiles, respiration of, 407.
 Repulsion, 8—laws of, 233, 289—electrical, 230, 233—magnetic, 289.
 Residual charge, 243.
 Resin, 595.
 Resin gas, 439.
 Resin soap, 595.
 Resinous electricity, 237.
 Resinous substances, determination of, in soils, 653.
 Resistance—limiting angle of, 94—of fluids, 119.
 Resolution of forces, 24, 34.
 Resonance, 154.
 Respiration, 405—produces carbonic acid, 405—of reptiles, and fishes, 407—of plants, 557—hepatic, 407.
 Resultant,—force, 25—axis, 217.
 Retarding force, 13.
 Retina, 212.
 Retort, 384.
 Retort stand, 386.
 Return shock, 254.
 Reversion—of motion, 90—of steam engines, 358, 360.
 Revolution of the earth, shown by pendulum, 76.
 Revolving bodies, 33.
 Rhodium, 526—compounds of, 526—detection of, 527.
 Rhombohedral system, 382.
 Rhumbs, 290.
 Rifling of guns, 92.
 Right-handed—screw, 67—crystal, 228.
 Right prismatic system, 382.
 Rigidity of cordage, 97.
 Rochelle salt, 579.
 Rock crystal, 310.
 Rock salt, 310—prism, 310.
 Rods, rate of their vibration, 161.
 Roman balance, 45.
 Roots, 553.
 Rotary engines, 353—difficulties attending, 354.
 Rotation—of the earth, shown by pendulum, 76—produces magnetism, 302.
 Rotation, electro-magnetic, 294.
 Rubber, affects nature of the electricity produced by friction, 239.
 Rust, how prevented, 497.
 Ruthenium, 527—compounds of—detection of, 527.
 Saccharic acid, 600.
 Saccharine fermentation, 602, 603.
 Saccharohumic acid, 600, 620.
 Saccharohumine, 600.
 Sacculmic acid, 599.
 Sacculmine, 599.
 Safety lamp, 409.
 Safety tube, 385.
 Safety valve, 339.
 Sal-ammoniac, 427.
 Salicine, 617.
 Salpeterfrass, 634.
 Salt, why it prevents putrefaction, 619.
 Salt of lemons, 567.
 Salts, 373—basic, 374—neutral—acid—alkaline, 375—indispensable to plants, 559.
 Sand bath, 391.
 Sap, 557, 559—ascend of, 128.
 Saturated solution, 377.
 Sausages, poisonous, 618.
 Savary's mode of raising water, 331.
 Scales, for weighing, 43.
 Scapement, 72.
 Scapement wheel, 72.
 Schlerotic coat, 212.
 Screw, 66—threads of, 66—pitch of—right-handed—left-handed—solid—hollow—differential, 67—endless—micrometer, 68—of Archimedes, 135, 136.
 Screw paddles, 136.
 Screw press, 67, 250.
 Sea breezes, 165.
 Sea-weed, 628, 633.
 Sebacic acid, 590.
 Secondary—bow, 207—current, 300—helix, 302—compounds, 372—crystalline forms, 382.
 Sedlitz powders, 579.
 Seed, 562—monocotyledonous, &c., 562.
 Seed crops, why they exhaust, 563.
 Seeds, require air, and moisture, but not light, 563.

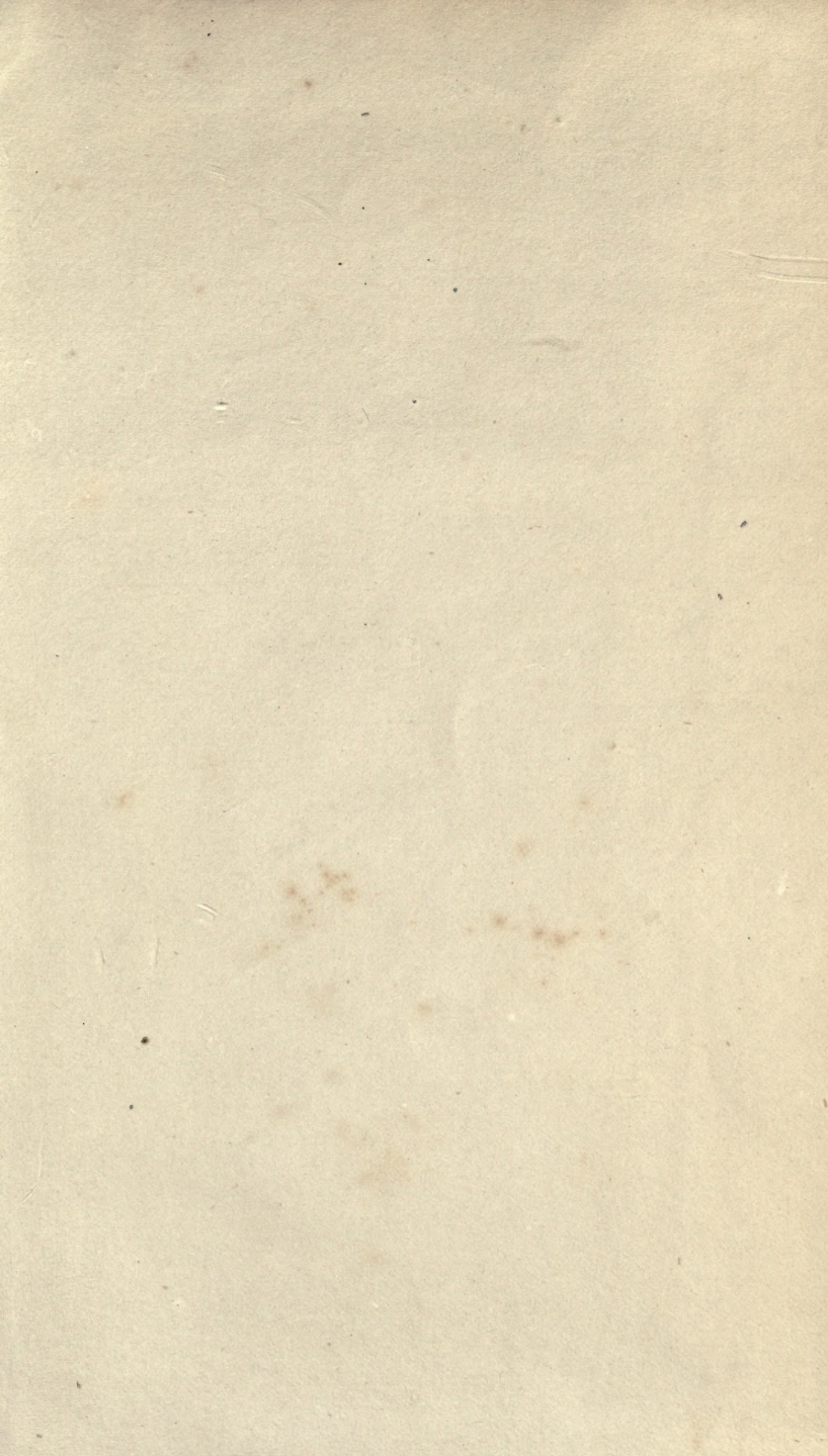
- Selenite, 226.
 Selenium, 447—detection of, 448.
 Self-discharging electrometer, 251.
 Self-luminous bodies, peculiarity of their light, 168, 219.
 Self-registering thermometer, 319.
 Sensible—electricity, 231—heat, 315, 322.
 Sepals, 560.
 Sesquioxide, 371, 398.
 Sessile leaves, 557.
 Shadows, 167, 208.
 Shaft, 56.
 Sharps, 156.
 Shear steel, 499.
 Shell, 448, 483—constituents of, 632.
 Ship, why it obeys the helm, 38.
 Ships, burned by lime, 375.
 Ship's course, 290.
 Shock—electric, 251—galvanic, 282—direct—return, 254.
 Shocks, machine for giving, 300.
 Short sight, 215.
 Shot, manufacture of, 126.
 Shrubs, ashes of, 623.
 Silex, 463—determination of, in water, 641—in soils, 654, 656.
 Silicates, double and triple, of alumina, 656.
 Silicic acid, 463.
 Silicon, 463—compounds of, 463.
 Silver, 528—compounds of—nitrate of—ammonio-nitrate of—detection of, 529.
 Silvering of mirrors, 511.
 Silver gauze, 278.
 Single acting engine, 334.
 Single filter, 378.
 Single microscope, 179.
 Singlings, 605.
 Size, estimate of, 214.
 Sleepers, 360.
 Slide valve, 342, 351.
 Slot, 81.
 Small pox, virus of, 618.
 Smalt, 489.
 Smee's battery, 266.
 Smoke box, 337.
 Snifting valve, 332.
 Snow, prevents intense cold, 307.
 Soap, 593—earthy, and metallic, 588—hard—soft—of potash, 593—of soda, 593, 594—mottled, 594—grain—white—resin, 595—ammoniacal, 620—manufacture of, 594.
 Soda, 530—bleaching salt of, 454—carbonate of, 530—hyposulphite of—sulphate of—phosphate of—ammoniacal phosphate of, 531—detection of, in water, 637—determination of, in water, 643, in soils, 654, 655.
 Soda bread, 609.
 Soda soap, 594.
 Soda water, 432.
 Sodium, 530—compounds of, 530—detection of, 531.
 Soils, 622—analysis of—absorbent power of, 652—organic, 653, and inorganic constituents of, 654.
 Solanine, 558, 616.
 Solar microscope, 181.
 Solar spectrum, 193—irrationality of, 194—properties of, 195.
 Solder—hard, 491—soft, 504.
 Solid—screw, 67—ingredients, in water, determination of, 639.
 Solids, specific gravity of, 110, 112.
 Solomon de Causs' mode of raising water, 331.
 Soluble—glass, 470—albumen, 613.
 Solution, 376—aqueous—alcoholic—ethereal—saturated—used to separate substances—sometimes changes their nature, 377.
 Sorbic acid, 581.
 Sound, 152—medium of—conduction of, 152—velocity of—intensity of, 153—quality of, 155—reflection of—concentration of, 162—interference of, 163.
 Sound board, 163.
 Sources—of force, 36—of light, 166—of heat, 306.
 Spanish white, 481.
 Spatula, 386.
 Speaking trumpet, 162.
 Specific gravities, table of, 114.
 Specific gravity, 110—of solids, 110, 112—of fluids, 111, 112—of gases, 112—of vapours, 113—of water, 637, and soils to be analyzed, 112, 652.
 Specific gravity bottle, 112.
 Specific heat, 321.
 Speculum metal, 491.
 Speed—of fixed engines, &c., 347—of locomotives, 361.
 Spelter, 491.
 Spent ball, 2.
 Spermaceti, 592.
 Spindle, 56.
 Spines, 557.
 Spherical aberration, 191.
 Spodumene, 505.
 Spongiolles, 553.
 Spongy platinum, 412, 416, 518—unites gases, 412—affords a eudiometer, 416.
 Spontaneous combustion, 403, 450, 484, 587.
 Spouting fluids, 121.
 Spring tides, 6.
 Springs of carriages, 61—tones produced by, 161.
 Square wheels, 88.
 Squinting, 214.
 Stable equilibrium, 23.
 Staining of glass, 469.
 Stalactites, 433.
 Stalagmites, 433.

- Stamens, 560.
 Stannates, 535.
 Starch, 597—how formed, and changed in the plant, also its use in the latter, 559.
 Statical—pressure, 93—barometer, 148—electricity, 258.
 Statics, 1.
 Steam—its effective pressure, 333, 338—expansive action of, 351—proposed substitutes for, 363.
 Steam chest, 342.
 Steam cushion, 356.
 Steam dome, 337.
 Steam engine, 331—details of, 334.
 Steam pipe, 337.
 Steam space, 338.
 Stearates, 588.
 Stearic acid, 588.
 Stearine, 586, 588.
 Steel, 498—blistered—tilted—shear—cast—Damascus—combinations of, 499—hardening and tempering of, 500.
 Steel yard, 44.
 Stem, 555.
 Stibium, 476.
 Stigma, 560.
 Still, 389, 604.
 Stipe, 555.
 Stomata, 556.
 Stopped pipes, 160.
 Stream—quantity of fluid supplied by—velocity of, 125—lateral draft of, 125, 131.
 Strings—tuning of, 160—rate of vibration of, 161.
 Strontia, 532—determination of, in water, 643.
 Strontium, 532—compounds of—determination of, 532.
 Stuffing or packing box, 313, 342.
 Style, 560.
 Suberic acid, 589.
 Sublimation, 381.
 Subnitrate of bismuth, 447.
 Suboxide, 373.
 Succinic acid, 589.
 Sucking tube, 385.
 Suction pump, 148.
 Sugar, 598—production of, in plants, impeded by light, 558—cane, 598—grape, 600—of milk, 601—why it prevents putrefaction, 619.
 Sugar of lead, 503, 504—antidote for, 503.
 Sulphate—of ammonia, 427—of nitric oxide, 443, 444—of lime, 483—of copper, 492—of iron, 498—of potash, 422, 523—of soda, 422, 456, 531.
 Sulphite of ammonia, 427.
 Sulphocyanide of potassium, 573.
 Sulphoglyceric acid, 587.
 Sulphosaccharic acid, 600.
 Sulphovinic acid, 607.
 Sulphur, 440—compounds of, resemble oxides, 440—detection of, in organic substances, 646—determination of, 651.
 Sulphur salts, 373.
 Sulphuret—of ammonium, 427—of iron, 498—of potassium, 525.
 Sulphurets, 375.
 Sulphuretted hydrogen, 446—action of, on metallic compounds, 447—detection of, in water, 636—determination of, 638.
 Sulphuretted hydrosulphuret of ammonium, 427.
 Sulphuric acid, 442—absolute—solid, 442—action of, on organic substances, 565—detection of, 445, 636—determination of, in water, 639, in soils, 654, 655.
 Sulphuric ether, 607.
 Sulphurous acid, 441—it bleaches, 442—stops fermentation—reduces certain metals, 442—is a compound radical, 445.
 Sun, causes tides, 6.
 Sun and planet wheel, 83.
 Superphosphate of lime, 448.
 Supporters, 370.
 Surface—pressure of a fluid on, 100—nature, 239, and extent of, affects electricity, 243.
 Surfaces of fluids, 105.
 Suspension, point of, 23—of a pendulum, 72, 73.
 Suspension bridge—destruction of, 158—expansion of, 312.
 Swing wheel, 72.
 Sylvic acid, 596.
 Symbols, table of, 370.
 Sympathetic ink, 488.
 Sympathy, 157, 158—affects clocks, 158, and organ pipes, 159.
 Synthesis, 376.
 Syrup, 599.
 Systems—of levers, 46—of pulleys, 48—of wheels and axles, 53—of inclined planes, 65, 66—of crystallization, 381.
 Table—of cohesion, 8—of friction, 95—of the bulk of aqueous vapour, 113—of specific gravities, 114—of resistance, in fluids, 121—of pressures required to liquefy gases, 140—of the velocity of sound, 153—of the force of the wind, 165—of indices of refraction, 169, 193—of the lengths of the waves, &c., of coloured rays, 210—of angles of polarization, 221—of the numbers of plates necessary for polarization, 223—of electrical excitement, produced by friction, 239—of relative conducting power, 308—of radiating power, 309—of reflecting

- power, 312—of rates of expansion, 314—of the force of aqueous vapour, 323—of freezing mixtures, 330—of elements, symbols, and equivalents, 370—of the quantities of gases absorbed by charcoal, 429—of the comportment of metals with re-agents, 542—of substances connected with alcohol, 608—of the ashes of trees, shrubs, and herbs, 623—of the organic, 626, and inorganic constituents of the most common vegetable substances, 627—of French weights, and measures, 658.
- Table blow-pipe, 388.
- Tail water, 129, 131.
- Talbotype, 202.
- Tangential—force, 26—turbine, 134.
- Tannic acid, 582—detection of, 583.
- Tannin, 582—artificial, 583.
- Tartar emetic, antidote for, 583.
- Tartaric acid, 578—anhydrous—detection of, 579.
- Tartralic acid, 579.
- Tartrelic acid, 579.
- Tawing, 584.
- Teeth, 483—of wheels, 57—faces of—flanks of—epicycloidal—involute, 58.
- Telegraph, electric, 298.
- Telescope, 182—refracting—astronomical, 182—reflecting, 190—Cassegrainian—Newtonian, 191—magnifying power of, 182, 191—employed to measure distances, 183.
- Temperament, 159.
- Temperature—affects electricity, 238—modifies conducting power, &c., 305—of animals, 405—of plants, 560.
- Tenacity, 7—table of—increased by wire-drawing, 8—impaired by crystallization, 381.
- Tempering of steel, 500.
- Terbium, 533.
- Terchloride of azote, 428.
- Tests for—
 ammonia, 428, 637.
 bromine, 461, 636.
 chlorine, 452, 636, 647.
 cyanogen, 570.
 iodine, 460, 636.
 fluorine, 462, 636.
 nitric oxide, 419.
 oxygen, 419.
 acetic acid, 575.
 citric acid, 580.
 formic acid, 577.
 hydrocyanic acid, 570.
 gallic acid, 585.
 malic acid, 581.
 oxalic acid, 567.
 sulphuric acid, 445.
 tannic acid, 583.
 tartaric acid, 579.
- Tests—*continued*.
 aluminum, 476.
 antimony, 477.
 arsenic, 478.
 barium, 480.
 bismuth, 481.
 cadmium, 482.
 calcium, 484.
 cerium, 485.
 chromium, 486.
 cobalt, 488.
 columbium, 489.
 copper, 492.
 glucinum, 493.
 gold, 495.
 iridium, 496.
 iron, 501.
 lanthanum, 502.
 lead, 503, 505.
 lithium, 506.
 magnesium, 507.
 manganese, 508.
 mercury, 511.
 molybdenum, 513.
 nickel, 515.
 niobium, 515.
 osmium, 517.
 palladium, 517.
 platinum, 518.
 potassium, 525.
 rhodium, 527.
 ruthenium, 527.
 silver, 529.
 sodium, 531.
 strontium, 532.
 tellurium, 533.
 thorium, 534.
 tin, 535.
 titanium, 537.
 tungsten, 538.
 uranium, 539.
 vanadium, 540.
 yttrium, 540.
 zinc, 541.
 zirconium, 542.
- Theine, 617.
- Thenard's mode of restoring pictures, 447.
- Theory—of emission, 166—atomic, 397.
- Thermo-electric—battery—multiplier, 284.
- Thermo-electricity, 283.
- Thermometer, 315—air—differential—ordinary, 316—Fahrenheit's—Reaumur's—centigrade—De Lisle's, 318—Breguet's—self-registering, 319—construction of, 316—graduation of, 317.
- Thermometers, comparison of, 318.
- Thorina, 534.
- Thorium, 533—compounds of—detection of, 534.
- Threads, of a screw, 66.
- Throttle valve, 79, 342.

- Throw, of eccentric, 86.
 Tides—in the sea, 4—in the atmosphere, 7—in the interior of the earth, 307.
 Tilted steel, 499.
 Tin, 534—grain—block, 534—compounds of—peroxide of—protochloride of—detection of, 535.
 Tincture of galls, 583.
 Titanium, 536—compounds of—detection of, 537.
 Torricellian vacuum, 145.
 Torsion—electrometer, 233—galvanometer, 296.
 Tourmaline, 225.
 Trajacadanthine, 598.
 Tram plates, 360.
 Translucent bodies, 172.
 Transparent bodies, 172.
 Transpiration, 557.
 Traps, 99.
 Trees, ashes of, 623.
 Tribasic—acid, 374—phosphate of soda, 374, found in the blood, 405.
 Triplet, 180.
 Trisalt, 374.
 Tritoxide, 373.
 Trituration, 382.
 Trough, pneumatic, 390.
 Trumpet—hearing—speaking, 162.
 Trundle, 57.
 Trunk, 555.
 Trunnion, 353.
 Tube—safety—sucking—dropping, 385.
 Tubes—of locomotive boiler, 337—of caoutchouc, 386.
 Tubular bridge, 350.
 Tubulated—receiver—retort, 384.
 Tungsten, 537—compounds of, 537—detection of, 538.
 Tuning, of pipes, &c., 160.
 Turbine, 132—Borda's, 132—tangential—Poncelet's, 134.
 Twinkling of the stars, 170.
 Tympanum, 152.
 Type metal, 504.
 Tyrosine, 614.
 Ulmic acid, 620.
 Ulmine, 620.
 Umbilicus, 562.
 Uniaxial crystal, 226.
 Undershot wheel, 129.
 Undulatory theory, 166.
 Uniform velocity, 11.
 Universal—joint, 84—discharger, 250.
 Unstable equilibrium, 23.
 Uranium, 538—compounds of, 538—detection of, 539.
 Uranyle, 538.
 Urea, 571.
 Uric acid, 571.
 Urine—as a manure, 628—constituents of, 628, 629.
 Uryle, 572.
 Vacuum—torricellian, 145—in condenser, 345.
 Valve—safety, 339—slide, 342, 351—lead of—lap of, 343.
 Vanadium, 539—compounds of—detection of, 540.
 Vapour of water—bulk of, 113—force of, 323.
 Vapours, specific gravity of, 113.
 Varvicite, 508.
 Vegetable—mucus, 598—albumen, 612—jelly, 615—alkalies, 616—manures, 633.
 Vegetables, constituents of, 622.
 Velocity, 11—uniform—accelerated, 11—virtual, 40—of sound, 153, 162—of the wind, 165—of light, 167—of electricity, 236—change of, 87.
 Velocity combinations, 87.
 Vena contracta, 121.
 Venous blood, 405.
 Ventilator, 125.
 Ventriloquism, 164.
 Vermilion, 510.
 Vertical—movement, 78—water wheels, 128.
 Vibration, rate of, is fixed, 159.
 Vinegar, 574—aromatic, 575.
 Vinous fermentation, 602.
 Virtual—velocity, 40—focus, 170.
 Viscous fermentation, 602.
 Visible horizon, extent of, 106.
 Visual angle, 176.
 Vitreous—humour, 212—electricity, 237.
 Vitriol, oil of, 444.
 Volta's—electrophorus, 246—pile, or column, 263.
 Volume of a gas, affected by pressure, 148, by its thermometric, 321, and by its hygrometric state, 327.
 Washing bottle, 379.
 Washing of precipitates, 379.
 Waste port, 342.
 Water, 409—elements of, 400—frozen in a hot crucible, 10—compressible, 99—can scarcely be rendered quite pure, by distillation, 324, 453—a base, 373, 374—combines, in more than one proportion, 375—of crystallization, 376—dissolves solids, 377, 412—absorbs gases, 413—is made poisonous by lead, 503—is decomposed by plants, 558—when hard, is unfit for washing, 594—is necessary for putrefaction, 619—analysis of, 636.
 Water bath, 328, 391.
 Water-pressure engines, 134, 363.
 Water space, 338.
 Water wheels—vertical, 128—horizontal, 132—overshot, 128—breast—undershot, 129—power of, 131.
 Wax, 593.

- Wax moulds, 274.
 Waxy substances in soils, 653.
 Weather glass, 147.
 Wedge, 65.
 Wedgewood's—battery, 264—pyrometer, 320.
 Weighing of precipitates, 379.
 Weight, 16—of bodies in motion, 93—of the air, 139—atomic, 367.
 Wet bulb hygrometer, 326.
 Wheel and axle, 51.
 Wheels and axles, combinations of, 53.
 Wheels—different kinds of, 55—teeth of, 57—pitch of—pitch circles of—line of centres of, 58—of carriages, 59—dished, 61—elliptical—square, 88—broad rimmed, 91.
 Whiskey, 605.
 Whispering galleries, 162.
 White—lead, 504—flux, 523, 656—resin, 595.
 White of eggs, an antidote for corrosive sublimate, 512.
 White's pulley, 49.
 Wind, 164—action of, on sails, 37, 38—cause of, 164—force of, 165.
 Windlass, 53.
 Windmills, 36.
 Wind vane, 37.
 Wines, adulteration of, 503.
 Wolf, 160.
 Wolf's apparatus, 390.
 Wollaston's battery, 264.
 Wood, decay of, 620.
 Wood cuts, drawn by the photographic process, 206.
 Wootz, 499.
 Working point, 69.
 Worm, 604.
 Worts, 603.
 Xanthoproteic acid, 613.
 Xylodine, 611.
 Yeast, 602.
 Yttrium, 540—detection of, 540.
 Zinc, 541—amalgamation of, 259, 263, 266—flowers of—compounds of—chloride of—detection of, 541.
 Zinc blende, 541.
 Zircon, 227.
 Zirconium, 542—detection of, 542.



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